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OBSERVATIONS ON THE LIFE HISTORY OF THE ARMY CUTWORM, CHORIZAGROTIS AUXILIARIS [1]

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INTRODUCTION

The army cutworm (*Chorizagrotis auxiliaris* Grote) occupies a prominent place among the pests of staple crops in the Northwest. Serious outbreaks have occurred at irregular intervals, and more or less damage is done nearly every year. Our knowledge of the life history of the species has been very incomplete, and further facts are obviously needed. The purpose of the present article is to present the results of studies made during several years and particularly some observations made in 1915 on the egg-laying habits of the species, together with their bearing on the question of the number of broods in the annual cycle.

SCIENTIFIC NAME OF THE SPECIES

In previous years the writer has repeatedly reared to the adult stage larvæ which had been taken in destructive colonies of this insect. Among these he has found forms corresponding with descriptions of *Chorizagrotis auxiliaris*, *C. agrestis*, and *C. introferens*. Moths reared from much-rubbed parents caught in the fall of 1915, as recorded below, when determined were found to include at least two of these forms. Gillette [2] states that he had found these forms occurring together in colonies in Colorado. For these reasons and because *C. auxiliaris* has priority, this name has been used to designate this insect in the present paper.

PREVIOUS EXPERIMENTAL EFFORTS

The attempts of the writer to obtain information regarding the life history of this species, and particularly regarding the egg-laying habits, date back for several years, and a brief summary of these efforts may be

[1] Since completing this manuscript and just as it is about to be offered for publication, the writer received a copy of Strickland's excellent paper, which covers somewhat the same ground. (Strickland, E. H., The army cutworm, Euxoa (Chorizagrotis) auxiliaris Grote. Canada Dept. Agr Ent. Branch, Bul. 13, 1916.)

[2] Gillette, C. P. Some of the more important insects of 1903. *In* Colo. Agr. Exp. Sta Bul. 94 (Tech. Ser. 6), p. 6. 1904.

of benefit to any who have occasion to search for the eggs of other Noctuidae. On account of the irregular occurrence of the species, it has been quite impossible to depend upon getting a supply of living specimens for study when wanted, and a continuous effort in the search for the facts desired has been out of the question. In the nature of the case, instead of laying out and following a definite plan of study the successful pursuit of which would certainly lead to the results desired, it has been necessary to rely largely upon scattering observations made through several years as opportunity was afforded.

The first attempt to obtain the early stages was made in 1907, when, in the writer's first experience with an outbreak of the species, a large number of moths originating from larvæ which had been brought in during the fall, were reared during the winter in the insectary and were held in large Riley-type cages in order that they might have an opportunity to lay eggs. All of the moths died within a few days, and no eggs were laid. In the spring several hundred larvæ were brought in from grain fields and fed to maturity. The moths which emerged were left in the cages and given water and a variety of plants upon which to lay eggs. Again the moths died without laying eggs.

Several explanations for the failure suggested themselves. It was thought possible that the moths were not normal because of having been reared in confinement. A number of female moths were dissected for the purpose of examining the ovaries, and it was found that the ova were immature. The idea suggested itself that the failure to develop ova was the outworking of some little understood principle of periodicity in the occurrence of the species, and it was also thought that the absence of mature ova might be due simply to the lack of food after the emergence of the adults.

In the spring of 1910 there was a destructive colony of the larvæ 8 miles west of Bozeman, and plans were laid to recover a supply of the pupæ from the soil, allow them to emerge in confinement, and attempt to feed the adults on honey water to get them to grow ova. Our trip to the field to secure pupæ was not correctly timed, and the moths had already emerged. Accordingly, an attempt was then made to obtain moths by catching them at night near the same field. A special trap light was arranged, consisting of a wooden box 18 inches square and 12 inches high with an 8-inch circular hole in the top into which was inserted a large funnel-shaped tin with a 2-inch opening at the bottom. Above the funnel was placed an acetylene light from a stereopticon. This furnished a very strong light, and the night was favorable. The writer and an assistant went to the field, expecting to spend the night. They remained until between 12 and 1 o'clock, but only a few moths of any kind came, and none of *C. auxiliaris*. As no encouragement whatever was received, even though it was known that many thousands of

moths had emerged recently in the vicinity, the experiment was abandoned.

On numerous occasions attempts have been made to find moths in the field in the act of depositing eggs, either on crops or on vegetation on virgin sod. Much time has also been spent in searching for eggs on grasses, clover, alfalfa, stools of volunteer grain, and other cultivated plants. A few eggs of other noctuids have been found, but none of this species.

CAGE EXPERIMENTS

In April and May, 1915, there occurred in Montana a widespread and very severe outbreak of the army cutworm. Moving armies of the larvæ were reported daily, and many thousands of acres of fall wheat were eaten off during April and May, so that it was possible to obtain a supply of the living insects for study. Plans were made for a twofold effort in connection with the outbreak. It was decided to install several large cages outdoors and by any means possible to obtain adult moths of both sexes, place them in the cages, and attempt to feed and keep them alive until they should lay eggs, correlating the observations made in these cages with notes from the field.

Three large cages 24 inches square by 40 inches high were installed on the lawn near the insectary. These are of fine-mesh brass screening and are fastened to the earth by a broad baseboard which is inserted in the soil. A large door fills one side and in this door is a smaller one, sufficiently large to permit the insertion of the hand. On the 24th of April 28 larvæ were placed in cage 2 and 53 in cage 3. These worms had been collected from two fields at Willow Creek, Mont. They were fed regularly, but did not do well. It has been repeatedly found that it is difficult to rear a large proportion of these caterpillars when fed in a body in one cage. For this reason in rearing record specimens the writer has adopted the method of feeding the caterpillars individually in tin boxes and by so doing has brought nearly every individual to maturity. None of these caterpillars pupated in the large cages.

On June 10 about 300 pupæ which had been taken from the soil in a field at Willow Creek were brought to Bozeman and placed in cages 1 and 2. Not one of these emerged. When examined, they were dead and decayed. They had been placed individually in holes in the soil with the anterior end uppermost—a method which has been used with dry soil with much success in indoor rearing. It is possible that rains had closed the holes and injured the pupæ by puddling the earth around them. On the 20th of June, 13 moths which had been reared in the insectary were placed in cage 1, and on July 17 about 50 moths which were captured out of doors at Willow Creek were divided between cages 1 and 2. It was hoped that some of these would grow ova and deposit eggs Sponges saturated with honey water were placed in the cages daily and clover

blossoms were picked and put in fresh each day. A variety of plants in small pots were placed in the cages, and as some of these blossomed, it is probable that they would furnish more or less nectar on which the moths might feed. The general condition in these cages certainly more closely simulated complete liberty than could have been provided in the insectary.

The writer was at first much disappointed in the results obtained, for by repeated examinations of the vegetation which had been placed in the cages, he was unable to find any eggs. The moths lived on, however, and served a very valuable purpose in indicating that the normal life of the moth in the open might be much longer than had been thought. While the moths gradually died off during the summer, many were alive on August 16, and several were seen as late as September 21. A pair was seen in copulation on August 10. Since no eggs had been found in the cages, the fact that the moths lived on until so late also suggested that perhaps the period between the emergence of the adult and oviposition might be much longer than had been suspected. The writer therefore determined to look for the moths in the fields late in the summer.

After eggs had been found in the field, as recorded below, a very careful search on the soil in the cages was made, but without finding any eggs.

FIELD OBSERVATIONS IN 1915

During the season of 1915 the writer had an especially good opportunity to make observations in the field in connection with various trips to different parts of the State to aid farmers in the control of the cutworm and to collect material for the cages at Bozeman.

All through the summer, since some of the moths were still alive in the cages, the moths in the field or any clue that might indicate the time and place of egg laying were looked for. No moths were seen, except in or near fields which had been damaged, and even there none could be found a few weeks after the emergence of the moths. On July 16 and 17, moths were seen in great abundance at Willow Creek and were found hiding under clods of earth in the grain fields. At this time the last of the moths were just emerging, and some pupæ could yet be found. The same field was visited again on August 3, but no living moths could be found. Since the previous visit there had been a heavy rain, and by turning over clods of soil, many dead moths were found which had been trapped there. Since moths had been found so abundantly in this locality on July 16 and 17, it was thought that eggs also might be found. A careful, extended search, however, revealed none. Another search for eggs and young cutworms was made in this locality on September 21, but was entirely without results.

On July 17, the headlights of an automobile were used in the evening in an attempt to attract the moths in the field, but without much success.

In the early part of the evening one moth was caught, but a violent storm came up, preventing further search.

From this time until late in September, as recorded below, no moths were seen out of doors either at Willow Creek or elsewhere in the State. An electric-light moth trap was kept in use on fair, warm nights at Bozeman all summer, but no moths of this species were captured until late in September. Gillette[1] mentions what he considers to be two broods of the moths, one occurring between April 16 and July 10 and the other between September 13 and October 12. Wolley-Dod[2] records the capture of *C. auxiliaris*, *C. introferens*, and *C. agrestis* in Alberta, Canada, in June and July and states that one specimen each of *C. introferens* and *C. agrestis* was captured on September 9. One individual of *C. agrestis* was captured on May 19. Gillette also points out that he had been unable to find fully developed ova in the females of the first brood, though hundreds were dissected and examined, while dissected specimens of the fall brood, almost without exception, contained fully formed ova. This observation is of much importance and has been verified by the present author as stated elsewhere. It gives strong support to the conclusions of the present paper regarding the number of broods in the annual cycle. It also indicated that the ova are developed on food obtained as an adult rather than as a larva.

OBSERVATIONS ON THE EGG-LAYING HABITS OF THE SPECIES

On September 30 Assistant Entomologist J. R. Parker, of the Montana Station, while out on the college farm, saw noctuid moths flying in fair abundance. One was captured and brought in. On close examination it turned out to be a much-rubbed female of *C. auxiliaris*. Mr. Parker and the writer returned to the field at once to watch the moths. They were laying eggs in abundance directly upon the soil—not on plants, as had been expected. During the next few days extended definite observations on the egg-laying habits of the species were made on the college farm.

Several pieces of land had been recently plowed and harrowed. One field of 10 to 12 acres had been particularly well prepared for seeding some days earlier and was nearly free from vegetation, though a few grains and weed seedlings and grasses were to be found. The moths were seen in abundance on the soil in this field in fair weather day after day.

Egg laying was confined to the warm afternoons, and the moths were most active in the latter part of the day, from 3 o'clock until sunset. The mornings in October in Bozeman are generally quite cold, but a few warm forenoons occurred during which an unsuccessful attempt was made to observe egg laying in the field. By looking toward the west into

[1] Gillette, C. P. Some of the more important insects of 1903. *In* Colo. Agr. Exp. Sta. Bul 94 (Tech. Ser. 6), p. 6. 1904.

[2] Wolley-Dod, F. H. Preliminary list of the Macro-Lepidoptera of Alberta, N.-W. T. *In* Canad. Ent., v. 37, no. 2, p. 49. 1905.

the sun's rays during the late afternoon many moths could be seen flying or walking along the surface of the soil. The moths were repeatedly seen to fly into the field from the grasslands or stubble fields adjoining and stop in the tilled field, where they immediately began to lay eggs. Several times they laid eggs on the bare earth of the roads on the college farm.

The moths also laid eggs in one field on the college farm just after it was plowed. Not once was a moth seen to lay eggs on any green plant or in any green field or stubble field; nor were any eggs found in such fields. Again and again, while watching the moths laying eggs at close range in the tilled field, they were seen to pass close by different kinds of vegetation without pausing. It was perfectly evident that they preferred to lay the eggs in the soil. By being careful one could witness the egg laying in detail by following along on hands and knees as a moth alternately paused to lay eggs and walked for a short distance. By far the greater number of the eggs were placed on the surface of the soil, often on small clods of earth, the moth standing on the clod and bending the abdomen downward and often tucking the eggs on the underside of the clod. Generally one or two eggs were laid on one spot, a few seconds being taken for the process. Sometimes but not always the moth frisked the tip of the abdomen back and forth sidewise repeatedly across the spot where the eggs were laid, thus dusting them and leaving a few scales from the clothing of the insect. The bright, glistening-white eggs are thus obscured. Some of the eggs were laid just beneath the surface of the soil. This could be done only where the soil had been pulverized, and in accomplishing it the ovipositor is thrust down through the surface of the soil and left for a few seconds. It is difficult to find such eggs under the surface of the soil, even when the spot is seen and the examination is made at once. One egg was found on a piece of dead straw. Generally only one to three were laid in one place, but in one case a moth deposited many eggs in soft soil within the space of a few square inches.

From the number of moths seen on the field and the number of days egg laying continued, it was roughly estimated that at least one or two eggs per square foot were laid in this field. By carefully searching a spot selected at random, eggs, almost certainly of this species, could be found. Four different persons, including the writer, have found eggs on the soil without having seen the moths deposit them. Both sexes were found among the moths captured in the field during the period of egg laying.

From these observations it can not be said that the eggs are necessarily always laid on bare or broken soil. In fact, it is almost certain that they are sometimes laid in abundance where newly plowed or newly harrowed soil is not available. A field of alfalfa badly infested with these cutworms was seen in Utah by the writer in May of the present year (1916), but no soil that could have been plowed last fall was anywhere in the vicinity. However, the stand of alfalfa was very scattering, leaving

much bare soil between the plants. A much-traveled road near by probably did not account for the presence of the worms. It seems more likely that the eggs were laid on the bare patches of soil in the alfalfa field.

There can be no doubt as to the specific identity of the moths that were observed, for many taken in the act of egg laying were carried into the insectary and placed in chimney cages, where they laid eggs in large numbers. Larvæ hatching from these eggs were reared to maturity, and the moths were obtained and all identified as belonging to this species. A few moths of other species were seen in the field during these observations, but none except *C. auxiliaris* were seen to deposit eggs.

ATMOSPHERIC TEMPERATURE DURING OVIPOSITION

No very definite temperature limits to oviposition can be stated. Thermometers were taken into the field and observed from time to time as the moths were being watched. The temperature during the rapid oviposition generally ranged between 55° and 70° F. A temperature of 60° to 70° at 4 or 5 o'clock p. m., with little or no wind stirring, insured great activity of the moths. When the sun set, the temperature dropped rapidly, and the moths sought shelter under clods and in cracks in the soil, very few being found still active in a temperature between 45° and 50°. Egg laying ceased at about 40°, though the moths were seen to fly at lower temperatures if disturbed. Whether or not the moths would continue active after dark if the temperature were favorable can not be stated.

DESCRIPTION OF THE EGG

Viewed from above, the egg is circular in outline: but when viewed from the side, it is very nearly elliptical, the shape varying from an ellipse only by being slightly flattened on the side on which it rests, which is opposite the micropile. It measures 0.62 mm. in diameter by 0.52 mm. in height. The color when the egg is first laid is white tinged with yellow, but before hatching the dark embryo shows through, giving the effect of a darker color. Surface markings on the chorion are very obscure. They are invisible under a hand lens magnifying 16 diameters. When viewed by reflected light under a compound microscope or under the high power of a binocular microscope, a very faint reticulation may be seen. This is more distinct in the shells of hatched eggs, in which the pattern often may be very clearly seen. No ridges radiating from the apex or upper part of the egg, such as may often be seen in noctuid eggs, have been found in this species.

EGG-LAYING HABITS IN CONFINEMENT

The moths taken into the insectary and put in cages were quite irregular in their egg laying. In general, two or three days were passed without laying eggs; then a large number were laid within a few hours, after which the moths soon died. Clover blossoms were placed in the cages,

and the moths were seen to be apparently feeding on the nectar. In the field during the same period the moths were seen to pause in their flight from field to field and visit blossoms of such plants as mustard and clover.

The various lots of eggs were allowed to hatch and the larvæ were reared in the greenhouse during the winter. Critical notes on instars and stadia were also made for later publication.

DURATION OF THE EGG-LAYING PERIOD

It is not probable that the writer observed the very beginning of the egg-laying period when, on September 30, the first moths were seen to be laying. It is altogether probable that the period began some days earlier, and there is no absolute evidence that egg laying had not been in progress for some weeks. It is quite clear, however, that the period closed about October 14, when a cold spell with rain occurred. When the weather cleared again, observations were resumed in the fields, but only a few scattering moths could be found, even though the temperature was favorable. October 8 was noted as the date on which the maximum activity of moths and egg laying was observed, and some eggs were laid as late as October 12. It may be safely stated that the egg-laying period is two weeks or more in duration.

NUMBER OF EGGS LAID

A detailed record of the number of eggs laid by individual moths was not made, as several circumstances in connection with the methods used interposed to make this difficult. The writer was influenced also by the fact that the moths had laid a part of their full number of eggs before being confined, which made it impossible to get complete data. The largest number actually counted was 252, all laid during one night, but this probably falls considerably below the actual maximum number. From this the number varies down to a very few, which may be accounted for in part by the moths having laid eggs in the field before being captured. The moth that laid 252 eggs died soon after and was dissected, the ovaries showing many immature ova.

DURATION OF THE INCUBATION PERIOD

The writer has complete records of the duration of incubation in 23 lots of eggs. A part of these were kept in the insectary and a part in an outdoor shelter. The minimum period recorded is 9 days, the maximum 21 days, and the average 16.77 days. The wide variation shown is striking and can probably be explained. The egg lots were kept during incubation in small tin boxes which were opened and examined daily. It was observed that many eggs were badly shrunken, and the dark embryos could be seen through the chorion. It was decided to add a very small amount of water to each box, as it was feared that the eggs would die from dryness. Accordingly, 1 to 3 drops of water were placed

in each of the boxes and the eggs hatched within a few hours. It seemed to be clear that incubation had been completed some days earlier in some of the lots, but that the young caterpillars had been prevented from issuing until sufficient moisture was present. Thus, some hatched in 9, while others hatched in 21 days. Those in the outdoor shelter hatched as soon as those inside. It is probable that 9 or 10 days is about the correct incubation period.

No field data on the incubation period are available. Repeated searching revealed no newly hatched caterpillars in fields where numerous eggs were known to have been laid. It is very interesting to note also that no larvæ could be found this spring in the field on the college farm where the eggs are known to have been laid last fall.

LARVAL FEEDING IN THE FALL

Only scattering records of larvæ in the fall are available, but these are of considerable interest. In the fall of 1906 the very small larvæ of this species did some damage in the northern part of Gallatin Valley. Several lots of the larvæ were received at the Experiment Station in November, and reports of their occurrence had reached it in October. One lot was reared to the adult condition. This is the only case known here in which the larvæ have attracted the attention of the farmers in the fall, and in this case the knowledge of their presence served as a useful warning of their coming in destructive numbers the next spring. The fall of 1906 was unusually dry and warm, the mild weather continuing until late. The larvæ continued feeding until December 6.

On November 4 and 5, 1915, an assistant was able to find larvæ in nearly every field of grain examined in Fergus County. They were not very abundant, but were easily found by the holes eaten in the leaves. At this time the worms were very small, probably in the second instar. Cold weather occurred soon afterward and larval feeding must have ceased. On April 10, 1916, some of the same fields were visited again and the larvæ were still very small. They certainly were very much smaller than on the same date in 1915. It is clear that there is a considerable variation in the size reached before winter sets in and, hence, in the size of the larvæ in the spring.

HIBERNATION OF THE INSECT

From the foregoing and from Johnson's observations[1] it is clearly evident that the insect hibernates as a partly grown larva.

It has been stated above that in the fall of 1906 the larvæ fed until December 6. The feeding of the caterpillars ceased with the coming of a snowstorm. A field which had been visited only a few days before and which was known to contain many larvæ was examined after this storm. The snow was swept away with a broom, and the larvæ were found on

[1] Johnson, S. A. Cutworms. *In* Colo. Agr. Exp. Sta. Bul. 98, p. 15. 1905.

and near the surface of the soil in a torpid condition. When taken into the hand, they immediately warmed up and began to crawl. There was apparently an absence of any quiescence other than torpor induced by cold.

DURATION OF LARVAL FEEDING IN THE SPRING

In Montana the larvæ resume activity with the beginning of the growth of vegetation, which is generally in the latter part of March or early in April. In 1910 the first larvæ from the field were sent in on April 24. In 1915 the first to be received at the Experiment Station came on April 2. By April 15 the station was receiving many urgent requests for information regarding control, indicating that the worms were very active. They continued in abundance in the field until about the third week in April and gradually disappeared until early in May, as indicated by many observations in the field and by the correspondence. In 1915 several lots of larvæ from various parts of the State were reared in the insectary and began pupating on April 22 and continued until May 19, when the last had transformed. The greater part of these had pupated by May 10.

In general, the occurrence of the larvæ in "armies" may be said to extend from April 1 to May 1.

PUPATION AND EMERGENCE OF ADULTS

From the notes of the writer on the rearing and more especially from information regarding the disappearance of the larvæ in the field it is clearly evident that by the last week in April in average years the larvæ are rapidly disappearing. Pupation takes place in an earthen cell about 2 inches under the surface of the soil. The pupa always rests with the anterior end uppermost, and the molted skin lies beside it.

The duration of the pupal stage, as indicated by the rearing records of many isolated individuals in the insectary and not including rearings conducted during the winter months in an artificially heated greenhouse, varies from 43 to 63 days and averages 54.7 days. From field observations the duration of this stage has been determined to be approximately 60 days. The first week in May clearly marks the height of pupation out of doors. On July 16 and 17 fresh moths were found in great abundance in the fields at Willow Creek, while only a very few pupæ could be found It may be safely assumed that the last of the moths were emerging about this date, and the height of emergence was during the first week in July.

The writer several times has noted that a small advantage of temperature markedly hastens the appearance of the moths of this insect. If kept in a cool place, the emergence of the moths may be greatly delayed. That the time of emergence varies in different seasons is shown by the fact that on July 8, 1910, in attempting to get pupæ 8 miles west of Bozeman it was found that the moths had all emerged. This was an early, dry season. It is quite clear that the first of the moths appear in June.

NUMBER OF BROODS

From the foregoing observations it is clearly evident that the army cutworm passes through but one annual life cycle. There is not time enough for a second brood to occur between the appearance of adults in the early part of July and the laying of eggs about October 1. Nine days is the sortest incubation period the writer has noted. The only accurate data of the writer regarding the duration of the larval stage were obtained by rearing to maturity in a heated greenhouse in the winter of 1915–16 the various lots of eggs laid by moths in October, 1915. It is believed that the larval period in the greenhouse was probably shorter than it would have been out of doors even in the summer time. The longest period recorded was 118 days, the shortest 96, and the average was 104.06 days. As stated above, the shortest pupal period secured in the indoor rearings was 43 days, which added to the minimum periods gives 148 days, while from July 1 to October 1 there are only 92 days, thus leaving a difference of 56 days. Moreover, no larvæ have been found at any time during the summer which might belong to a second brood.

Observations given in previous paragraphs which have a bearing on this question may be recapitulated. Moths caught in June and July are bright and fresh; those caught in the fall are rubbed and faded. The ovaries are immature in July, while in September and October they are mature. Moths placed in cages at Bozeman in July and given honey water and clover blossoms daily lived until late in September.

If it be assumed that the brood of moths emerging in June and July live over until fall, meantime growing ova, then the 12 months of the year are all accounted for in one life cycle of the insect.

SUMMARY

From the foregoing observations the life history of the army cutworm (*Chorizagrotis auxiliaris*) may be summarized as follows:

(1) Egg laying was observed from September 30 to October 12, but possibly occurred for some weeks previous to September 30.

(2) The moths deposit the eggs directly upon the bare soil.

(3) The incubation period is about nine days indoors, but hatching may be delayed by lack of sufficient moisture.

(4) The larvæ feed for a variable period in the fall which terminates with the onset of winter.

(5) The insect hibernates as a partly grown larva.

(6) Activity is resumed by the larvæ with the beginning of plant growth in the spring.

(7) The larvæ feed until about the first week in April, when they enter the earth for pupation.

(8) The moths emerge from the latter part of June to the middle of July.

(9) The moths live over until fall, growing ova on food obtained as adults.

(10.) The army cutworm is single brooded in Montana.

APHIDOLETES MERIDIONALIS, AN IMPORTANT DIPTEROUS ENEMY OF APHIDS

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INTRODUCTION

The economic importance of *Aphidoletes meridionalis* Felt was established when the larvæ of this cecidomyiid fly were first observed by the writer at La Fayette, Ind., on June 29, 1912, destroying large colonies of *Aphis setariae* and *Hyalopterus pruni* on plum (*Prunus* spp.). Subsequent observations in the States of Iowa, Wisconsin, Illinois, Michigan, and Indiana emphasize its value as an efficient agency in the natural control of Aphididae.

While most of the data reported in this paper were obtained during July and August, 1912, it was impossible to obtain a specific determination of the species from specimens used in the experiments at that time, but during the past season (1915) Dr. E. P. Felt has kindly determined it as *Aphidoletes meridionalis* from living adults reared from larvæ collected in the same locality and attacking the same kinds of aphids as those used in the experiments of 1912. *Aphidoletes meridionalis* was described by Dr. Felt in 1908 from adults reared from larvæ predacious on the tulip-tree aphis (*Macrosiphum liriodendri* Monl.).[1]

ECONOMIC IMPORTANCE, NATURAL CHECKS, AND APHIDS ATTACKED

The fact that each larva may destroy dozens of aphids and that these flies are remarkably prolific makes this predator very important and valuable. Many instances were observed where aphid colonies were apparently completely destroyed. For example, on June 6, 1915, the undersides of leaves of catnip (*Nepeta cataria* L.) in the writer's yard were completely covered with *Aphis gossypii*, and at that time *Aphidoletes meridionalis* was just making its appearance in numbers, the eggs and larvæ up to half or possibly two-thirds grown being abundant. A week later (June 13) very few aphids remained, and most of the predacious larvæ had made cocoons on the undersides of leaves between the leaf veins or on the ground at the base of plants, and a few days later only very rarely could a live aphid be found. A few syrphid larvæ, an occasional coccinellid larva or adult, and some aphidiine parasites were present, but the control of the aphis was apparently due entirely to *Aphidoletes meridionalis*.

[1] Felt, E. P. Studies in Cecidomyiidae II. In 23d Rpt. State Ent. N. Y., 1907, p. 384, 397. 1908. (N. Y. State Mus. Bul. 124).

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Sept. 4, 1916
K—42.

Although the fly is prolific and constitutes an effective check to the increase of aphids under favorable conditions, the adults are very frail and easily destroyed by unfavorable weather conditions, such as beating rains. They do not, as a rule, make their appearance in appreciable numbers until the latter part of May and probably can not, therefore, be considered as being so generally reliable as a natural means of control as are the hymenopterous enemies belonging to the subfamily Aphidiinae.

This cecidomyiid is a general feeder, attacking almost any species of aphid available, but more often feeding on those which live gregariously upon their hosts. The writer's records show that it attacks the following species: *Aphis asclepiadis* Fitch., *A. avenae* Fab., *A. cardui* L., *A. gossypii* Glov., *A. helianthi* Monl., *A. maidis* Fitch *A. setariae* Thos., *Chaitophorus negundinis* Thos., *Hyalopterous pruni* Fab., *Macrosiphum granarium* Kibby, *M. pisi*, Kalt. *M. sonchella* Monl., *Myzus persicae* Sulz., *Phorodon humuli* Schr., *Rhopalosiphum sonchi* Oestl., *Siphi flava* Forbes, *Siphocoryne pastinacae* L., and *Toxoptera graminum* Rond.

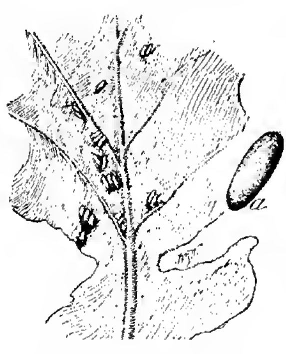


FIG. 1.—*Aphidoletes meridionalis*: Eggs in situ on leaf of rape; *a*, egg, greatly enlarged.

HISTORICAL SUMMARY

Aside from systematic discussions, very little has been written about *Aphidoletes meridionalis*. There can be no doubt that the larvæ predacious on *Macrosiphum pisi* and referred to by Fletcher in his report for 1900 [1] as a species of Diplosis were *Aphidoletes meridionalis*, and this seems to be the first authentic record in economic literature. A short account of the habits of probably the same species as the one under discussion is given by Webster and Phillips,[2] who refer to it as an enemy of *Myzus persicae* and of the spring grain aphis or "green bug" (*Toxoptera graminum*) and predict that it may possibly become an important factor in the control of *T. graminum*. The writer [3] has referred to this species as an active enemy of the pea aphis (*Macrosiphum pisi*) and other writers have barely referred to it as predacious on aphids.

[1] Fletcher, J. T. Report of the entomologist and botanist. 1900. *In* Canada Exp. Farms Rpts. 1900, p. 212. 1901.

[2] Webster, F. M., and Phillips, W. J. The spring grain-aphis or "green bug." U. S. Dept. Agr. Bur. Ent. Bul. 110, p. 133. 1912.

[3] Davis, J. J. The pea aphis with relation to forage crops. U. S. Dept. Agr. Bul. 276, p. 54. 1915.

LIFE HISTORY AND DESCRIPTIVE NOTES

The eggs (fig. 1) are very small, elliptical oval, chrome orange in color, paler at the extremities, and measure 0.104 mm. in width and 0.313 mm. in length. They are laid in clusters of from 1 to 12 on foliage amongst a colony of aphids or may be deposited on the dorsum of the aphid itself, as many as 7 having been noted on a single aphid. The number of eggs laid by individual females was determined in two cases (Table I), and it will be noticed that these females laid 116 and 125 eggs each, respectively. The cages used for obtaining eggs were of the ordinary "chimney" type and the results certainly were not above normal and more likely were below normal. The exact length of the egg stage was not accurately determined, but from the approximate records given in Tables I and II and from some more exact miscellaneous records the length of the egg period averages about three days.

TABLE I.—*Records of eggs of two individual females of Aphidoletes meridionalis; La Fayette, Ind., August, 1912*

Cage No.	Date male and female were introduced into cage.	Date first lot of eggs were counted.	Number.	Hatching and rearing records.	Date second lot of eggs were counted.	Number.	Hatching and rearing records.	Date third lot of eggs were counted.	Number.	Hatching and rearing records.
7654(4)	1912. Aug. 1	Aug. 3	55	Eggs hatching Aug. 6; adults Aug. 22–23.	Aug. 5	22	Eggs hatching Aug. 8; adults Aug. 23–24.	Aug. 7	11	Adults Aug. 25–26.
7654(5)	[a]Aug. 2	Aug. 5	17	Eggs hatching Aug. 8; adults Aug. 24.	Aug. 7	22	Adults Aug. 23–24.	Aug. 9	38	Adults Aug. 25.

Cage No.	Date male and female were introduced into cage.	Date fourth lot of eggs were counted.	Number.	Hatching and rearing records.	Date fifth lot of eggs were counted.	Number.	Hatching and rearing records.	Date of death of Aphidoletes female.	Total number of eggs.
7654(4)	1912. Aug. 1......	Aug. 11..	20	Adults Aug. 25–27.			......	Aug. 11?...	116
7654(5)	[a]Aug. 2...	Aug. 12....	33	....	Aug. 1[illegible]	11	......	Aug. 1[illegible]...	125

[a] This pair was observed in copula at 7.30 p. m. on Aug. 2.

Immediately upon hatching the larva attacks the most convenient aphid, and at this stage of its life more often pierces the body of its host from beneath, usually between the legs. After sucking the body fluids from the first aphid and killing it, the larva leisurely moves to another, this operation being continued until it becomes full grown. The larva always seems to move about cautiously, at the same time quickly thrusting its tongue-like anterior end in and out and to all sides much as does a syrphid larva. When it locates its host it thrusts its proboscis into the

aphid and sucks the body fluids until the aphid is dead and more or less shriveled. The victim seldom notices the presence of the larva, judging from outward indications. After the larva becomes one-third grown it usually punctures the aphid at one of the articulations of the legs, a favorite point of attack being at the membranous joint connecting the tibia and femur (Pl. CX, fig. 2). If the larva attacks the aphid at an articulation as above described, the latter seldom notices the attack; but if the proboscis of the larva touches the wrong places, the aphid kicks about more or less for a few seconds. As a rule, several minutes are required for the larva to pump out most of the body juices of the host, but this time varies, depending upon the relative sizes of the larva and its host. The aphid is often discarded by the larva soon after it has been killed and long before it has been sucked dry.

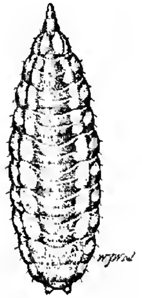


FIG. 2.—*Aphidoletes meridionalis:* Larva, dorsal view. Greatly enlarged.

To the naked eye the larva of *Aphidoletes meridionalis* (fig. 2) closely resembles such common cecidomyiids as the cloverleaf midge (*Dasyneura trifolii* Loew), but differs slightly in coloration, being usually of a pale orange, varying from pale pinkish to a rather deep orange, and when mature measures approximately 3 mm. in length. The length of the larval period varies, depending upon the temperature and food supply; but according to observations of the writer it is between 7 and 11 days.

When fully mature the larva spins a loose cocoon of silk mingled with aphid remains, attaching it to the leaf between the veins; or it descends to the ground and at or near the surface spins its cocoon (fig. 3), incorporating with it particles of dirt and trash. The larva pupates shortly after constructing the cocoon. The pupa (fig 4), which is of an orange color, resembles other related cecidomyiids; it measures 2 mm. in length and its cocoon is 2.25 mm. long and 1.125 mm. wide. The length of the pupal stage varies, according to observations, between 6 and 9 days.

FIG. 3.—*Aphidoletes meridionalis:* a, Cocoon formed on surface of ground; b, cocoon formed on a leaf blade.

The adult (Pl. CX, fig. 1) may be popularly described as a small, frail midge, much resembling, to the casual observer, (*Dasyneura*) *Neocerata rhodophaga* Coq. the destructive rose midge, or the clover-seed midge (*Dasyneura leguminicola* Lintn.). Its length is approximately 1.4 mm. for the male, and 1.8 mm. for the female; the body is pale and the abdomen has a decided pinkish tint. Copulation and egg laying seem to occur

at night—at least they have been observed by the writer only at night, although the cages were examined much more frequently during the day.

Egg laying continued over a period of about 10 days in "chimney" cages, and the length of life of the midge under the same conditions was about 14 days. Several unsuccessful attempts were made to induce unfertilized females to lay eggs, although fertilized females laid eggs readily, indicating that this species is probably not parthenogenetic.

FIG. 4.—*Aphidoletes meridionalis*: Pupa, lateral view. Much enlarged.

As will be seen from Table II, the total length of the life cycle from egg to adult varied, in the region in which it was studied, from 15 to 29 days, the average normal life cycle being about 18 to 20 days. The seasonal number of complete generations has not been determined, but there are evidently at least six complete generations annually, the winter being passed as larvæ and possibly also as pupæ within the cocoons.

TABLE II.—*Length of life cycle of Aphidoletes meridionalis; La Fayette, Ind., July-August, 1912*

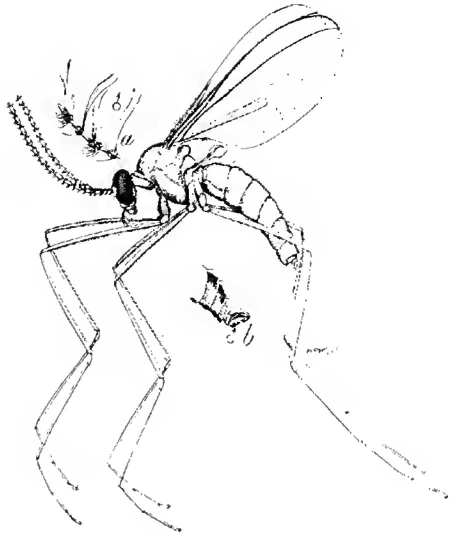
Cage No.	Eggs laid—	Eggs hatched—	All larvæ finished feeding—	Cocoons noticed—	Adults issued—	Total life cycle.	
						Minimum.	Maximum.
	1912.					*Days.*	*Days.*
7654(1)c	July 15-16	July 17-18			Aug. 5-14	20	30
7654(1)d	July 17-18	July 20		July 25-29	Aug. 5-13	18	27
7654(3)a	Aug. 1	Aug. 5-6	Aug. 13		Aug. 21	20	
7654(4)	Aug. 9-11				Aug. 26-27	15	18
7654(4)a	Aug. 1-3	Aug. 6	Aug. 15		Aug. 21-23	19	22
7654(4)b	Aug. 3-5	Aug. 7-8	do.		Aug. 22-24	17	21
7654(4)c	Aug. 5-7		Aug. 14		Aug. 25-26	18	21
7654(5)a	Aug. 3-7	Aug. 7-8			Aug. 24	19	21
7654(5)b	Aug. 5-7				Aug. 23-24	16	19
7654(5)c	Aug. 7-9				Aug. 25	16	18
7654(2)a	July 15-16	July 18	July 25	July 24-26	Aug. 1-15	16	29
7654(2)b	July 16-17			July 26	Aug. 1-7	15	22

PLATE CX

Aphidoletes meridionalis:

Fig. 1.—Adult female: *a*, Antenna of male, showing structure; *b*, tip of male abdomen. Greatly enlarged. (Redrawn after Webster and Phillips.)

Fig. 2.—Larva attacking a pea aphis (*Macrosiphum pisi*). (From Davis.)



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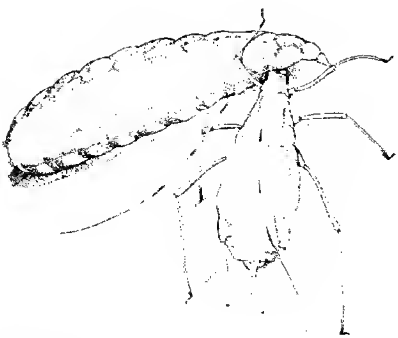

2

INFLUENCE OF BARNYARD MANURE AND WATER UPON THE BACTERIAL ACTIVITIES OF THE SOIL

By J. E. GREAVES, *Bacteriologist*, and E. G. CARTER,[1] *Assistant Bacteriologist, Department of Bacteriology, Utah Agricultural Experiment Station*

INTRODUCTION

The application of barnyard manure to a soil brings about a far-reaching change within the soil. It has been found that, as an average, 1 ton of barnyard manure contains 10 or 12 pounds each of nitrogen and potassium and 2 or 3 pounds of phosphorus. It also carries other substances of less importance which may be directly utilized by the growing plant or which may react with substances within the soil, changing their solubility. This direct and indirect nutritive value of a manure is not its only function, for it changes greatly the physical structure of the soil. It improves the tilth of a clay soil by increasing the granulation within it, while in a sandy soil it tends to bind the particles together, making it less porous. Each of these changes react upon the water-holding capacity and the capillarity of the soil, greatly altering the aeration of the soil and with it the temperature.

The biological changes which the manure produces in the soil, especially when small quantities are added, may be more far-reaching than either the chemical or physical changes which it produces. Every pound of manure carries with it to the soil millions of bacteria. Many of these will find the new conditions unsuited for their growth, but some will continue to multiply, and in so doing not only will decompose the constituents of the manure but also will greatly alter other organic and inorganic substances of the soil. Hence, the bacterial content of the soil is changed both quantitatively and qualitatively. There are added with the manure many new species, and the changed physical and chemical conditions of the soil due to the manure will greatly modify those already present, for the microflora and fauna originally present in the soil were due to specific properties of the soil.

This changed flora and fauna will in turn change the chemical and physical properties of the soil still more. Acids are generated, which react with insoluble constituents, rendering them soluble. Gases are formed, which change the air within the soil; and in these reactions heat is generated, thus changing the temperature of the soil. The metabolism of the bacterial cell requires nutritive substances, among which are water

[1] The authors wish to express their appreciation of the kindness of Dr. F. S. Harris, of the Utah Experiment Station, in placing at their disposal the plots used in this investigation and also the records of treatment and yield, for it is this assistance which has made possible this investigation.

and the elements essential to plant growth. Some soluble constituents will be changed to insoluble and some inorganic to organic. All of these changes must be reflected in the yield of the crop produced.

This investigation was undertaken to throw more light on some of these changes, especially the influence of manure in the presence of varying quantities of water upon the bacterial activities of the soil, and it may be seen by an examination of the more important literature on the subject that with respect to the control of both manure and moisture this experiment is unique.

HISTORICAL REVIEW

That the addition of manure to a soil increases the number of bacteria has been shown by Remy[1] (37, p. 660–733) and Fischer (13, p. 358). Caron (6) found that the number of bacteria present depends not only upon the manure added but upon the cultural methods and the crop grown upon the soil. Fabricius and Von Feilitzen (12) found that bacteria increased in the soil on the addition of manure and that a direct relationship existed between the temperature of a soil and the number of bacteria found in it. That the temperature of the soil is influenced by the addition of manure is shown by Wagner (47), who observed that manure increased the temperature of soil from 1 to 2.8 degrees centigrade, depending on the kind and condition of manure added. Troop (44) noted an average increase of 5 degrees in temperature of soil receiving 25 tons per acre of manure over unmanured soil. Petit (35), however, claimed that, while there was at first an increase in the temperature of manured soils, later it became lower than the unmanured. Stigell (41) concluded that bacteria under favorable conditions for development retarded the conduction of heat in soils and thereby reduced the temperature changes due to the variation in the outside temperature. This in a way might neutralize the effect of manure, for Hecker (20) found that while the temperature of soil to which well-rotted manure had been added was higher than adjacent unmanured soil during the day, the opposite was true during the night. Grazia (17) stated that manures greatly increase the temperature of the soil. King (26) found that a definite increase in bacterial activity occurred with increased temperature, but that an excessive moisture content greatly reduced the number of bacteria in a soil. Engberding (11) claimed that manure increased the number of bacteria in a soil, but he considered that the moisture content had a greater influence on numbers than did temperature. That the moisture content greatly influenced bacterial activity was shown by Dehérain and Demoussy (9), who found that the bacterial action of a soil was at its maximum when a rich soil contained 17 per cent of water, but that it decreased if the proportion of water fell to 10 per cent or rose to 25 per

[1] Reference is made by number to "Literature cited," p. 925–929.

cent. With soils less rich in humus a somewhat higher proportion of water was necessary to retard oxidation to any marked degree. In a manured soil the coarse manure tended to cause the surface soil to dry out, while fine manure prevented evaporation. King (25) observed that manured land contained more moisture throughout the year than unmanured soil, and this was reflected upon both the bacteria and the crop. The bacteria themselves may play a small part in this difference in moisture content, as was shown by Stigell (42), who found that bacteria decreased the speed of evaporation of water from Petri dishes. Hiltner and Störmer (24) claimed that the addition of manure to a soil brought about a marked increase in the number of bacteria. The temperature, cultural methods, and crop had an influence, but it was not nearly so pronounced as that produced by the manure. Dafert and Bolliger (8) stated that the difference in moisture did not have to be great to produce a great change in the oxidation going on in the soil, for a distinctly measurable difference was noted when the moisture varied 1 per cent.

Brown (4), in a study of the influence of manure on the bacterial activities of a loam soil, found that applications of manure up to 16 tons per acre increased the number of bacteria and also the ammonifying and nitrifying powers of the soil. The greatest increase in the processes was brought about by small applications of manure, 8 to 12 tons to the acre. He observed a close relationship between the ammonifying powers of the soil, the bacterial content, and the crop produced on the soil.

Temple (44) stated that the addition to a soil of 10 tons of cow manure per acre greatly increased the number of bacteria in the soil, but that a greater increase occurred when a sterilized manure was applied. This, however, is not in keeping with the results obtained by other investigators, for Hellström (22) concluded that manures possessed a fertilizing effect aside from the quantities of fertilizer constituents contained within them; and this, he claimed, is their great bacterial content. And Stoklasa (43) found that manure increased the bacterial content and activity of a soil and was greater with small, frequent applications of manure than with large applications made at longer intervals. Moreover, Lipman and others (31) observed that the bacteria conveyed to soil in small quantities of manure were valuable in bringing about a more rapid decomposition of a green-manure crop, while Briscoe (3) said that a direct relationship existed between the organic matter added to a soil and the bacterial count and that a light dressing of manure with green manure produced a marked effect upon both the crop and the bacterial count. Bacterial cultures added with the green manure gave just as pronounced an effect as did the stable manure. Lemmermann and Einecke (29), however, obtained no increase on adding stable manure with green manure. This may be due to the different kind of manure used, for Emmerich and others (10) claimed that a more favorable effect

was obtained from the use of well-rotted manure than fresh manure. This, they claimed, was due to the production in the latter of formic, acetic, and butyric acids, indol, skatol, and hydrogen sulphid, which are toxic to the plant. Under some conditions the large quantities of carbon dioxid liberated from the rapidly decomposing fresh manure may be valuable in rendering soluble plant food. Bornemann (2) found that soil constantly supplied with carbon dioxid through a pipe buried in the ground gave an increase in yield of 12.2 per cent over the crop grown on untreated soil. Wollny (52) has shown that manure greatly increased the carbon-dioxid production in a soil.

Moll (33) claimed that the season of the year and not the kind of fertilizer used, nor even the weather conditions, is the principal factor in determining the peptone decomposition, nitrification, and nitrogen fixation of a soil. According to Wohltmann, Fischer, and Schneider (51), ammonification, nitrification, and nitrogen fixation were all more or less increased by the application of manure. Lipman (30, p. 135) found that the peptone-decomposing power of a soil was greatly increased by the application of manure. Heinze (21) found that manure was especially beneficial to the nitrifying organisms. Warington (48) reports that much more nitric nitrogen was found in the soil of plots which had received annually for 38 years a dressing of 14 tons of manure to the acre than in any of the other manured or unmanured plats. While Stevens (39) found that nitrification was much more active in manured than in unmanured soil, Frankfurt and Duschechkin (14) observed an increase in nitrification only on those manured plots on which the yield had increased. Velbel (46) has shown that the chief factors controlling nitrification in fallow soil were the humus and the humus-nitrogen content of the same, the nitrification having increased directly with the humus. He noted, however, a certain amount of denitrification at first, but later in the summer nitrification became more rapid on the manured than on the unmanured soil, the effect of the manure being still perceptible after four years. Some investigators (23, 36, 50) have reported a reduction of nitrates, but the quantity of manure applied was excessive, or else of a very coarse nature, or the soil very poorly aerated. Barthel (1) found that nitrification did not take place in the presence of soluble organic matter, but he considered it unlikely that sufficient quantities of soluble organic constitutents occurred in normal agricultural soils to interfere greatly with nitrification. Niklewski (34) claimed that nitrification occurred in solid stable manure when there was not much liquid present. He stated that on the first day some nitrite bacteria were present and at the end of four weeks there were 10,000 per gram. Associated with these were nitrate bacteria which were identical with those isolated by Winogradsky. Millard (32), however, was unable to find many nitrifying bacteria in manure.

Many of the cases in which individuals have reported a disappearance of nitrates in soil are due to synthetic reactions, the nitrates being built up into complex proteins. For Gerlack and Vogel (15) have shown that there are several varieties of bacteria in the soil which have the power of converting ammonia, nitrites, and nitrates into insoluble proteins.

The processes of ammonification, nitrification, and nitrogen fixation, being due to the action of micro-organisms, are intimately associated with the moisture content of the soil; hence, we find in many cases this is the limiting factor. Guistiniani (16) found in sandy soil that the rapidity of nitrification of ammonium sulphate was directly proportional to the amount of moisture present when this varied from 0 to 16 per cent. While Roche (38) has shown that irrigation supplying from 15 to 25 per cent of water to a soil furnished the most favorable conditions for nitrification, Coleman (7) found nitrification most active in a loam soil with a moisture content of 16 per cent. It was greatly retarded when the water content was reduced to 10 per cent or raised to 26 per cent. It is also interesting to note that he found that with a high moisture content soluble organic matter became injurious to nitrification.

The nitrogen-fixing organisms would also be influenced by the water content, as shown by Warmhold (49), who stated that when the water content went below 10 per cent there was no nitrogen fixation and in some cases there was a decided loss of nitrogen. Krainskiï (27) said that nitrogen fixation was at its height in soils containing fairly small quantities of water. Later he (28) stated that the higher the humus content the larger the water content of the soil required for optimum nitrogen fixation. Increasing the organic matter of the soil was not found to increase nitrogen fixation, although there was an increased bacterial activity. Hanzawa (18) found that the humus of stable manure could be used as a source of energy by some nitrogen-fixing bacteria.

PLAN OF EXPERIMENT

The plan of the experiment is such that it can be divided into three parts. The first deals with the bacterial activities of a soil receiving a definite amount of manure and measured quantities of irrigation water and kept fallow in pots under vegetation house conditions. In this the moisture content could be accurately maintained by the weekly weighing and the replacing of lost moisture. The variation in temperature and moisture of this series would not be as great as it would be under field conditions. The second part deals with the bacterial activities going on in a soil under field conditions, the soil receiving known quantities of manure and water but kept fallow. The third part deals with soil of the same field under irrigated conditions and manurial treatment the same as the second part, but producing a crop.

COMPOSITION OF SOIL

The investigation was conducted either on soil from the Greenville Experiment Farm or on the farm itself, which is situated 2 miles north of Utah Agricultural College. The soil represents a type found in large areas in the Great Salt Lake Basin. It is of a sedimentary nature, being derived from the weathering of the mountain range near by, which consists largely of limestone and quartzite deposited by the streams as they flowed into the now extinct Lake Bonneville. The soil is situated at the foot of the main delta thus formed and consists of fine sand and coarse silt of fairly uniform chemical and physical composition to a great depth. The chemical and physical analysis of the soil is given in Table I. The chemical analysis was made according to the official methods of the Association of Official Agricultural Chemists,[1] while the physical analysis was made by means of the Yoder soil elutriator.

TABLE I.—*Chemical and physical composition of the soil of the Greenville (Utah) Experiment Farm*

Chemical composition.		Physical composition.	
Constituent.	Per cent.	Constituent.	Per cent.
Insoluble residue	41.46	Coarse sand	0.21
Soluble silica	.62	Medium sand	9.63
		Fine sand	30.04
Total	42.08	Coarse silt	32.25
Potash (K_2O)	.67	Medium silt	12.30
Soda (Na_2O)	.35	Fine silt	6.25
Lime (CaO)	16.88	Clay	7.62
Magnesia (MgO)	6.10	Moisture	1.60
Oxid of iron (Fe_2O_3)	3.03	Soluble and lost	.10
Alumina (Al_2O_3)	5.64	Specific gravity	2.67
Phosphoric acid (P_2O_5)	.41	Apparent specific gravity	1.23
Carbon dioxid (CO_2)	19.83	Water-soluble salts	.06
Volatile matter	5.60		
Total	100.69		
Humus	.53		
Nitrogen	.139		

The soil has been analyzed to a depth of 10 feet and was found to be very similar in both chemical and physical composition to that given in Table I. There were, however, slightly greater quantities of acid-soluble material in the lower foot sections. The humus and nitrogen of the deeper soil was slightly less than in the first foot. The physical composition is practically the same to a depth of 10 feet. The soil is exceptionally rich in phosphorus and potassium, but low in nitrogen and humus. The calcium and magnesium contents are exceptionally high and one may conclude that for this reason the soil is unproductive; but just the reverse is true, for the soil is very fertile and even with its low nitrogen and humus content produces excellent crops.

[1] Wiley, H. W., ed. Official and provisional methods of analysis, Association of Official Agricultural Chemists. As compiled by the committee on revision of methods. U. S. Dept. Agr. Bur. Chem. Bul. 107 (rev.), 272 p., 13 fig. 1908. Reprinted 1912.

METHOD OF SAMPLING THE SOIL

All possible precautions against the contamination of one sample by another were taken in collecting them. The surface soil to a depth of half an inch was scraped off by means of a sterile spade. A hole 12 inches deep was dug, and a slice of soil to this depth was taken from the side of the hole and placed in a sterile mixing pan. This process was repeated from four or five places in the field and then the contents of the pan carefully mixed by means of a sterile spatula. From this composite sample a representative portion, about 5 pounds of soil, was placed in a sterile ore sack and conveyed to the laboratory for analysis.

Before each sampling, the spade, mixing pan, and spatula were all carefully sterilized by heat from a plumber's torch, thus preventing the transfer of organisms from one soil to another. The samples were immediately transferred to the laboratory, partly air-dried in the dark, and then ground in a sterile mortar, all coarse rock being removed. The analysis was begun in all cases within 24 hours of the time of taking samples.

METHODS OF SOIL ANALYSIS

The number of organisms were determined by growing on modified synthetic agar having the following composition:

1,000 c. c. of distilled water.
10 gm. of dextrose.
0.5 gm. of dipotassium phosphate (K_2HPO_4).
0.2 gm. of magnesium sulphate ($MgSO_4$).
2 gm. of powdered agar per 100 c. c. of media.

After the samples of soil had been carefully mixed by shaking 100 gm. were weighed on a sterile watch glass, using a small sterile spatula. This soil was transferred to 200 c. c. of sterile water and shaken for one minute, 1 c. c. of this suspension transferred to 99 c. c. of sterile water, and the dilution continued with 9 c. c. of sterile water. The plates were made so as to give a dilution of 1 to 20,000 and 1 to 200,000. They were incubated at 28° C. for four days and then counted. No attempt was made to differentiate between bacteria and molds, but all were listed together as total numbers of colonies.

The ammonifying power of the soil was determined by weighing 100-gm. portions of the soil and 2 gm. of dried blood into sterile tumblers and covering them with Petri dishes. The dried blood was thoroughly mixed with the soil by means of a sterile spatula and the water content made up to 18 per cent with sterile water. The samples were incubated at 28° to 30° C. for four days and the ammonia determined by transferring to Kjeldahl flasks with 250 c. c. of distilled water, adding 2 gm. of magnesium oxid and distilling into *N/10* sulphuric acid. The determinations were all made in duplicates and compared with sterile blanks.

The nitrifying power of the soils was determined in tumblers, like the ammonifying power, except that they were incubated for 21 days. The moisture content was made up weekly to the initial 18 per cent.

At the end of the incubation period each soil was transferred with 250 c. c. of distilled water to a 1-pint Mason fruit jar. Two gm. of powdered lime were added and the jar placed in the shaking machine for 10 minutes, after which it stood in the closed jar until clear. This never required over two hours. At the end of this time an aliquot part, 100 c. c., was measured into a flask and the nitrates determined by the aluminum reduction method (5).

The nitrogen-fixing powers of the soil were made by weighing 5-gm. portions of the soil into 500 c. c. Erlenmeyer flasks containing 100 c. c. of Ashby solution. These, together with sterile blanks, were incubated for 18 days and then the total nitrogen determined by the Kjeldahl method. All determinations were made in triplicate.

POT EXPERIMENTS

Dry soil, to a depth of 12 inches, was taken from one of the unmanured plots of the Greenville Farm and very carefully mixed and used as the soil for the pot experiments. This soil, together with the required quantity of well-rotted barnyard manure, was packed into the pots. Moisture determinations were made upon the mixtures and then sufficient water added to make up to the required moisture content. The pot and contents were weighed and the moisture content made up weekly to the initial content. The pots were kept on shelves within the building for four months, and then the various determinations were made on each sample as outlined. The temperature of the soil was taken each time before making it up to the moisture content. The manure was applied at the rate of none, 5, 10, 15, 20, and 25 tons to the acre. An acre of soil was considered as weighing 2,000,000 pounds. Each ton of the manure contained 738 pounds of dry matter, 3.04 pounds of phosphorus, 13.70 pounds of potassium, and 16.08 pounds of nitrogen. The moisture was kept at 12.5, 15, 17.5, 20, and 22.5 per cent by weight. Duplicate pots were used in every case with each specific treatment. At the end of the experiment three separate analyses made on each pot, so that each reported result is the average of six closely agreeing determinations. The results are given in Table II.

The number of bacteria developing on synthetic agar does not seem to have been greatly influenced by the various treatments. All counts are comparatively low. If, however, we average the results for all pots which received the same manurial treatment we find a greater number developed from the soils which received 25 tons of manure to the acre than from any of the others. Moreover, there is an appreciable difference in favor of those soils receiving from 10 to 20 tons per acre over the unmanured soil. The irrigation water apparently depresses the number of organisms, for the greatest number developed from soil receiving the least water; but here also the difference is not marked or regular. The

average counts from the pots receiving the same quantities of irrigation water are with 12.5 per cent of water, 4,251,000; 15 per cent of water, 3,838,000; 17.5 per cent of water, 3,882,000; 20 per cent of water, 3,352,000; and 22.5 per cent of water, 3,680,000.

TABLE II.—*Number of bacteria developing on synthetic agar and quantity of ammonia and nitric nitrogen formed in 100 gm. of soil and of nitrogen fixed in 100 c. c. of Ashby solution—pot experiments*

Treatment.	Number of colonies of bacteria.	Quantity of ammonia formed	Quantity of nitric nitrogen formed.	Quantity of nitrogen fixed.
		Mgm.	*Mgm.*	*Mgm.*
12.5 per cent of water; no manure	3,530,000	36.9	3.36	9.9
12.5 per cent of water; 5 tons of manure	3,300,000	27.9	5.81	10.3
12.5 per cent of water; 10 tons of manure	4,710,000	48.5	78.05	10.19
12.5 per cent of water; 15 tons of manure	2,810,000	49.1	88.55	9.94
12.5 per cent of water; 20 tons of manure	6,100,000	49.6	115.00	10.15
12.5 per cent of water; 25 tons of manure	5,060,000	60.5	110.55	9.73
15 per cent of water; no manure	3,360,000	37.6	4.90	10.19
15 per cent of water; 5 tons of manure	3,300,000	43.2	67.90	10.33
15 per cent of water; 10 tons of manure	3,660,000	49.0	84.87	11.50
15 per cent of water; 15 tons of manure	4,260,000	51.0	110.55	11.90
15 per cent of water; 20 tons of manure	3,720,000	57.1	113.42	11.02
15 per cent of water; 25 tons of manure	4,730,000	74.8	117.25	10.05
17.5 per cent water; no manure	3,800,000	37.4	3.49	10.57
17.5 per cent of water; 5 tons of manure	3,730,000	48.5	75.60	10.50
17.5 per cent of water; 10 tons of manure	4,330,000	48.6	88.21	11.40
17.5 per cent of water; 15 tons of manure	4,050,000	54.7	108.85	9.59
17.5 per cent of water; 20 tons of manure	2,020,000	60.9	111.80	9.60
17.5 per cent of water; 25 tons of manure	4,460,000	60.9	124.40	9.83
20 per cent of water; no manure	3,730,000	28.8	4.20	9.15
20 per cent of water; 5 tons of manure	2,860,000	50.0	73.32	10.36
20 per cent of water; 10 tons of manure	4,050,000	54.4	78.14	10.81
20 per cent of water; 15 tons of manure	3,430,000	65.4	106.55	11.20
20 per cent of water; 20 tons of manure	3,230,000	66.7	113.00	10.46
20 per cent of water; 25 tons of manure	3,230,000	67.9	125.70	10.60
22.5 per cent of water; no manure	3,730,000	30.2	7.85	10.51
22.5 per cent of water; 5 tons of manure	4,400,000	48.8	65.74	10.57
22.5 per cent of water; 10 tons of manure	3,030,000	60.8	81.19	11.83
22.5 per cent of water; 15 tons of manure	3,130,000	63.8	118.50	10.45
22.5 per cent of water; 20 tons of manure	4,530,000	63.1	119.30	10.95
22.5 per cent of water; 25 tons of manure	3,260,000	64.6	126.65	10.89

Both the water and the manure applied make a marked difference in the ammonifying powers of the soil. It is lowest in those pots which received no manure and gradually increases when 5, 10, 15, 20, and 25 tons of manure are applied. The water likewise has a noticeable effect on the ammonifying powers of the soil. In the unmanured soil it increases until 20 per cent of water is applied, at which point it reaches its maximum. When more than this quantity of water is applied, the ammonification is retarded. It is not as great when 22.5 per cent of water is applied as in the presence of only 12.5 per cent. Similar results are obtained when various quantities of water are applied in the presence of 5 tons of manure per acre. Here the influence of the water is much more pronounced than it is in the absence of manure. It reaches its maximum effect when 20 per cent of water is applied. In the presence of 10 tons per acre of manure the higher percentages of water have much greater influence on the ammonifying powers of the soil than do the lower percentages of water. In the presence of 20 tons of manure the water also exerts a great influence, but here the higher percentages produce a depressing effect, which becomes very perceptible in the pots which have received 25 tons of manure to the acre. It is interesting to note that with 25 tons of manure 15 per cent of water gave better results than either higher or lower percentages of water. It is quite possible that the higher water content in the presence of large quantities of organic matter produce anerobic conditions which are not fully compatible with the best bacterial activities. The results are brought out more fully in figure 1, on the horizontal line of which is given the percentage of water applied to the soil, while on the perpendicular line is given the milligrams of ammonia produced in 100 gm. of soil.

If we consider the average quantity of ammonia produced in the unmanured pots as 100 per cent, that produced on the various manured pots becomes, with 5 tons of manure, 122 per cent; with 10 tons of manure, 140 per cent; with 15 tons, 152 per cent; with 20 tons, 160 per cent; and with 25 tons, 181 per cent. The average increase per ton of manure applied is greatest when 5 tons to the acre are applied and becomes gradually less as the quantity of manure applied becomes greater. If we consider the average percentage of ammonia produced in the soils receiving 12.5 per cent of water as 100, then the soil receiving 15 per cent of water produced 110 per cent; the soils with 17.5 per cent of water produced 111 per cent; the soils with 20 per cent of water, 123 per cent; and those receiving 22.5 per cent of water produced 119 per cent of ammonia—a gradual increase in the ammonia produced until the quantity of water applied exceeded 20 per cent.

The application of manure to a soil produces a very great increase in the nitrifying powers of the soil. The quantity of nitrates produced is very low in the soil receiving no manure but is greatly increased with the application of manure, even with so large a quantity as 25 tons per

acre. There is nothing in the results which would indicate denitrification in the presence of the largest quantities of organic matter applied in this experiment. The nitrifying powers of the soil increase with the water applied up to 17.5 per cent. Above this it has a slight depressing effect upon nitrification, probably caused by the production of an anerobic condition, but even with the highest percentage of water and 25 tons per acre of manure there is nothing in the results obtained which would indicate that denitrification had taken place. These results are brought out clearly in figure 2, in which is indicated on the horizontal line the per-

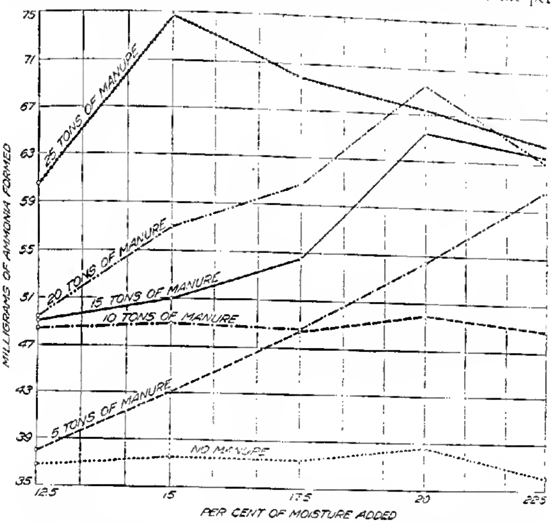

FIG. 1.—Curves of the ammonifying powers of soil in pots with varying quantities of manure and water

centage of water and on the perpendicular line the milligrams of nitric nitrogen produced in 100 gm. of soil.

If we take the average of the nitric nitrogen produced in the unmanured pots as 100, then that of the manured pots becomes with 5 tons of manure, 1,211 per cent; with 10 tons, 1,762 per cent; 15 tons, 2,240 per cent; 20 tons, 2,405 per cent; and 25 tons, 2,540 per cent. The greatest increase per unit of manure is produced when 5 tons of manure are applied. The water applied also produces a gradual increase, but here likewise the greatest increase per unit of water applied is greatest for the lowest application of water.

The nitrogen-fixing powers of all the soils are fairly high, but the influence of the water and manure is not as pronounced as it is upon the

ammonifying and nitrifying powers of the soil. The results as a whole indicate that the manure increases the nitrogen-fixing power of the soil and it is slightly higher when 10 tons per acre of manure are applied to a soil than when any of the other quantities are applied. Even those

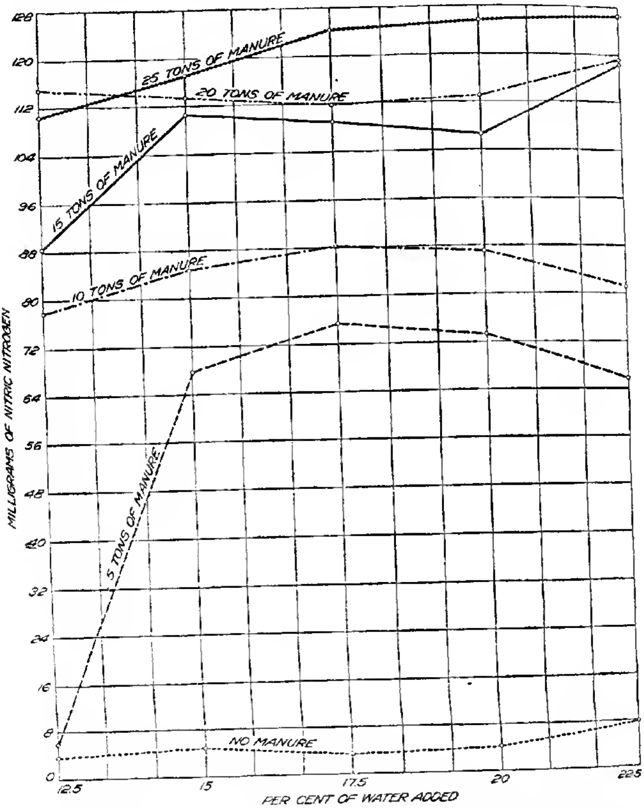

FIG. 2.—Curves of the nitrifying powers of soil in pots with varying quantities of manure and water.

pots receiving 5, 15, and 20 tons of manure per acre as an average fix more nitrogen than the unmanured soil.

The results taken as a whole indicate that the application of manure to soils in pot experiments influenced to a very great extent the ammonifying and nitrifying powers of a soil, but the influence upon the num-

ber of bacteria and nitrogen-fixing powers of the soil, while perceptible, is not as regular. The application of manure produced no difference in the temperature of the soil. The temperature of the manured and unmanured soils averaged very nearly the same throughout the experiment. The temperature of the pots receiving the least quantities of water averaged 1 degree centigrade higher than the soils receiving the greatest quantity of water.

The relationship existing in the various bacterial activities of the soil is brought out best by taking the average of each set of pots receiving the same quantity of manure and water. Then, if the bacterial activities of the pots receiving no manure and that of the pots receiving 12.5 per cent of water each be taken as 100 per cent and the others on a similar basis, we obtain a direct comparative value for each treatment. The results so obtained are given in Table III.

TABLE III.—*Bacterial activities of the soil in the presence of varying quantities of manure and water—pot experiments*

Treatment.	Bacteria.	Ammonia.	Nitric nitrogen.	Nitrogen fixed.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
No manure	100	100	100	100
5 tons of manure	99	122	1,211	103
10 tons of manure	111	140	1,762	110
15 tons of manure	100	152	2,240	105
20 tons of manure	116	160	2,405	103
25 tons of manure	117	180	2,540	101
12.5 per cent of water	100	100	100	100
15 per cent of water	90	111	118	108
17.5 per cent of water	91	113	121	102
20 per cent of water	79	123	121	104
22.5 per cent of water	87	119	123	108

It will be observed that the manure increases the number of bacteria developing upon the synthetic media, while the water depresses the number developing. In neither case is the regularity as great as could be desired. The ammonifying powers of the soil very regularly increases as the manure applied increases. The increase becomes less each time in a definite quantity as the manure increases. The water causes an increase in the ammonifying powers of the soil up until 20 per cent of water is applied; above this it causes a decrease. It would have been very interesting and practical to have added greater quantities of water to find whether it would have continued to depress the ammonification.

The quantity of nitric nitrogen systematically increases as the water and manure applied increase, and it may be seen, as would be expected, that there is a close correlation between the ammonification and nitrification. The nitrogen-fixing powers regularly increase up to 10 tons of manure per acre; above this they gradually decrease. The water tends

in all cases to increase the nitrogen gained. It will thus be observed that the manure applied increases the bacterial activities measured, while the water increased ammonification, nitrification, and nitrogen fixation, but depressed the number of colonies developing upon synthetic media. This would seem to be a very vital point against the count method. For we thus find a soil treatment increasing the main bacterial activities of a soil, but at the same time depressing the number developing in the laboratory. It would thus appear that the media used to make counts was better adapted for the development of organisms other than those which take the greatest part in the nitrogen transformation in the soil. On the other hand, it is quite possible that the increase in number may not keep pace with the increased physiological efficiency due to the application of water and manure. But this latter explanation would not account for the less number developing on the synthetic media.

FIELD EXPERIMENT ON FALLOW PLOTS

The fallow plots used in the field experiments were 7 feet wide and 24 feet long with a 4-foot walk between each two. The land was plowed in the fall, left over until spring, when a mixture of fairly well-rotted horse and cow manure was applied to the various manured plots. This was thoroughly disked or plowed into the soil. Water was applied to the plots from flumes as described in Utah Experiment Station Bulletins 115 to 120. They were kept free from weeds throughout the year. The quantities of water and manure applied to the various plots were as follows:

Four plots received no water and no manure.

Two plots received 5 inches of water, but no manure. The water was in two equal applications.

Two plots received 10 inches of water, but no manure. The water was applied in two equal applications.

Two plots received 20 inches of water, but no manure. The water was applied in four equal applications.

Two plots received 30 inches of water, but no manure. The water was applied in six equal applications.

Three plots received 40 inches of water, but no manure. The water was applied in eight equal applications.

All of the above were repeated with plots receiving 5 and 15 tons of manure to the acre. Hence, the series includes soils without manure, with 5 tons per acre, and with 15 tons per acre. The water applied varied from none up to 40 inches both with and without manure. This does not, however, represent the entire water reaching the soil, for there was an average annual precipitation of about 18 inches, most of which fell between the months of October and May. The precipitation from May to November did not exceed 5 inches, which, of course, would be

uniform for all plots. The plots had been treated since the spring of 1911 in the manner described; the bacteriological analyses were made during the summer of 1914 and 1915.

The results reported in Table IV giving the number of colonies of bacteria developing in four days on synthetic agar represent in every case the average of a number of determinations made at the times indicated.

TABLE IV.—*Number of colonies of bacteria developing in four days on synthetic agar—fallow plots*

Number of determinations.	Treatment.	Number of colonies.			
		May 12.	July 25.	Nov. 12.	Average.
12	No water; no manure	3,475,000	12,500,000	4,100,000	5,692,000
6	5 inches of water; no manure	3,000,000	7,600,000	3,700,000	4,767,000
6	10 inches of water; no manure	2,960,000	12,900,000	3,700,000	6,520,000
6	20 inches of water; no manure	3,030,000	12,600,000	3,950,000	6,527,000
6	30 inches of water; no manure	2,370,000	15,800,000	5,700,000	7,957,000
9	40 inches of water; no manure	5,660,000	11,860,000	3,800,000	7,107,000
6	No water; 5 tons of manure	3,570,000	23,500,000	4,300,000	10,457,000
6	No water; 15 tons of manure	7,700,000	20,000,000	4,800,000	10,833,000
3	5 inches of water; 5 tons of manure	4,000,000	11,800,000	6,600,000	7,467,000
3	5 inches of water; 15 tons of manure	5,600,000	14,200,000	11,200,000	10,333,000
3	10 inches of water; 5 tons of manure	4,600,000	19,000,000	7,600,000	10,400,000
3	10 inches of water; 15 tons of manure	6,000,000	28,000,000	4,000,000	12,667,000
3	20 inches of water; 5 tons of manure	4,300,000	18,000,000	6,600,000	9,633,000
3	20 inches of water; 15 tons of manure	4,400,000	27,400,000	9,800,000	13,867,000
3	30 inches of water; 5 tons of manure	6,200,000	21,200,000	4,400,000	10,600,000
3	30 inches of water; 15 tons of manure	3,600,000	29,400,000	3,200,000	12,067,000
9	40 inches of water; 5 tons of manure	4,450,000	14,066,000	5,933,000	8,150,000
9	40 inches of water; 15 tons of manure	4,600,000	19,933,000	6,200,000	10,244,000

It may be seen that the number of organisms are comparatively low during the spring, in no case exceeding 8,000,000, while in July the number becomes in most cases three or four times as many. In November the number developing is about the same as in May. This method therefore gives a maximum count in midsummer. The spring samples were taken after all frost had left the ground, while the fall samples were taken before

there occurred any very hard frost; consequently these numbers do not in any case represent the numbers found in frozen soil, which would probably be higher than any of the results herein reported.

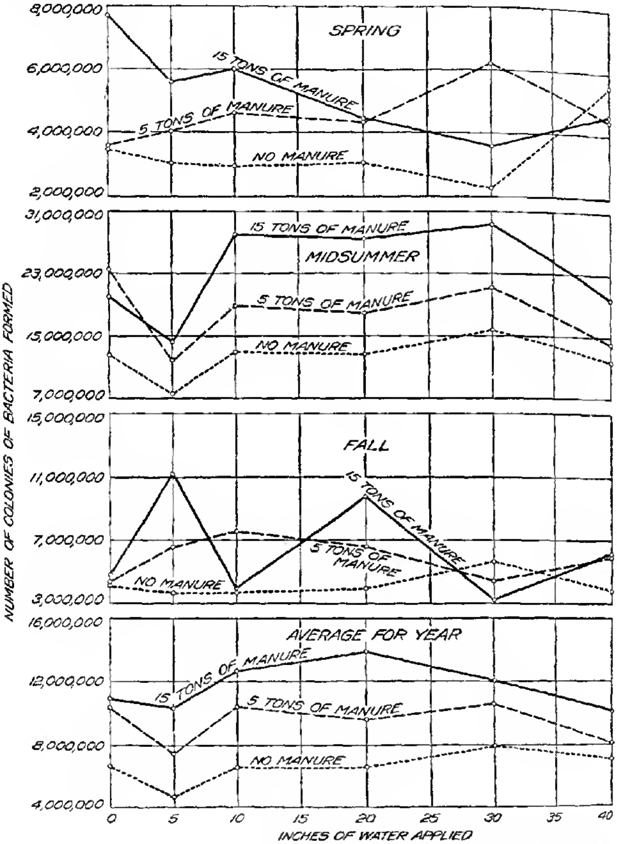

FIG. 3.—Curves of the number of colonies of bacteria developing from fallow soil with varying quantities of manure and water.

The results obtained for May show the unmanured soil to have few bacteria present, while the number in the manured soil increases as the quantity of manure increases. The water apparently had no marked effect upon their activity; or if it had, it had been obliterated during the winter

months. In July much the same order occurs. The soil receiving 15 tons of manure per acre contains more bacteria than that receiving 5 tons, and this in turn has more than the unmanured soil. Here the influence of the water becomes very marked, for there are many more bacteria in the soils receiving 10, 20, or 30 inches of water than in the soils receiving either no water or 40 inches. The excessive quantity of water, 40 inches, apparently checks the development of bacteria on the synthetic media.

The same results, in general, are obtained for November as for May and July, and with the exception of the abnormal results reported, where 10 inches of water were applied, the water has a pronounced effect even as late as November. This difference disappears during the winter, for we find a more uniform condition existing the next spring.

The average results for the unmanured soil show that more bacteria developed from the soil receiving 30 inches of water than from those receiving either more or less irrigation water. The manured soil, on the other hand, gave a maximum count from the soil receiving 20 inches of water. These differences are clearly brought out in figure 3. On the horizontal line is indicated the quantity of water applied, while on the perpendicular is given the number of colonies which developed. At the top of the figure are given the results for the spring, while below this in the order named for midsummer, fall, and the average for the year.

If we consider the average number of bacteria developing on synthetic media from the unmanured plots as 100 per cent, those developing on the manured plots become, with 5 tons of manure, 147 per cent, and with 15 tons, 177 per cent, showing that in so far as numbers are concerned the greatest effect per ton of manure applied is produced by the addition of 5 tons per acre. If we average the unirrigated plots and take these as 100 per cent, the others become, with 5 inches of water, 81 per cent; with 10 inches of water, 106 per cent; 20 inches of water, 107 per cent; 30 inches of water, 110 per cent; and 40 inches of water, 91 per cent. The maximum increase is apparently due to the application of 30 inches of irrigation water. But here, as was the case with the pot experiments, the results are not uniform.

The same plots were tested for ammonification, the results being given in Table V. In every case the result is the average of a number of closely agreeing determinations and are given as milligrams of ammonia produced in four days in 100 gm. of soil containing 2 gm. of dried blood.

The ammonifying powers of the soil, as may be seen from Table V, remain nearly constant throughout the season. There is, however, a big variation in the ammonifying powers of the different soils. In the spring the ammonifying powers of the unmanured soils are low. The quantity of ammonia formed in no case exceeds 57 mgm. per 100 gm. of soil. The water applied apparently had no perceptible influence upon the rate of ammonification. The quantity of ammonia produced by the soil receiving 5 tons per acre of manure is much higher than that pro-

duced by the unmanured, and the addition of water up to 10 inches produces a beneficial effect. The great effect, however, is noted on those soils which receive 15 tons of manure per acre. Here, also, the ammonifying powers are accelerated by the application of irrigatiou water up to 10 inches. Above this there is a depressing effect just as was noted in the pot experiments and can very likely be accounted for on the same grounds. In midsummer the influence of manure is just as perceptible as it is in the spring, and the influence of the water becomes much more regular, but still follows the same general trend that it did in the spring. In the fall the manure is found to exert almost quantitatively the same effect as it does in spring and midsummer. The depressing effect of the larger quantities of water during this season of the year is not as great as it is earlier in the year. But even here the higher applications (20 to 40 inches) cause a great falling off in the ammonifying powers of both the manured and unmanured soils. These results are brought out graphically in figure 4.

TABLE V.—*Quantity of ammonia (in milligrams) produced in four days in 100 gm. of soil containing 2 gm. of dried blood—fallow plots*

Number of determinations.	Treatment.	Quantity of ammonia.			
		May 12.	July 25.	Nov. 12.	Average.
12	No water; no manure	56.38	55.52	81.00	64.30
6	5 inches of water; no manure	54.78	47.60	77.10	59.82
6	10 inches of water; no manure.	50.99	46.25	64.65	53.96
6	20 inches of water; no manure.	49.56	44.65	62.80	52.33
6	30 inches of water; no manure.	46.62	44.30	61.70	50.87
9	40 inches of water; no manure.	49.87	42.83	63.97	52.22
6	No water; 5 tons of manure.	73.92	71.00	77.70	74.31
6	No water; 15 tons of manure.	92.65	82.95	82.25	85.95
3	5 inches of water; 5 tons of manure.	81.09	58.30	88.70	76.03
3	5 inches of water; 15 tons of manure.	116.55	97.60	92.00	102.05
3	10 inches of water; 5 tons of manure.	96.29	76.30	93.80	88.79
3	10 inches of water; 15 tons of manure.	129.20	118.50	112.00	119.90
3	20 inches of water; 5 tons of manure.	86.79	70.00	89.60	82.13
3	20 inches of water; 15 tons of manure.	111.59	108.5	106.6	108.89
3	30 inches of water; 5 tons of manure.	82.45	70.40	79.90	77.58
3	30 inches of water; 15 tons of manure.	112.63	....	105.80	109.24
9	40 inches of water; 5 tons of manure.	98.78	79.47	90.50	89.58
9	40 inches of water; 15 tons of manure.	106.51	91.63	100.33	99.49

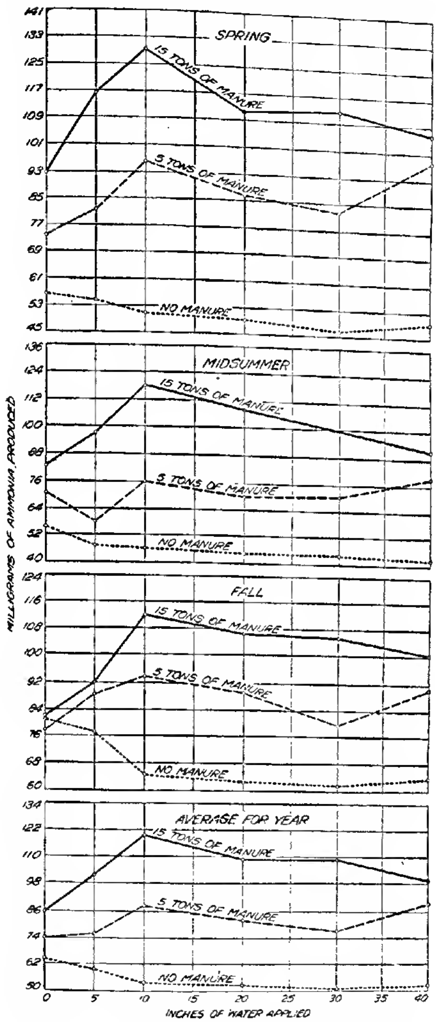

FIG. 4.—Curves of the ammonifying powers of fallow soil with varying quantities of manure and water.

If we take the average quantity of ammonia produced in the unmanured soil as 100 per cent and compare this with that produced in the manured soil, we find those soils receiving 5 tons of manure produce 147 per cent and those receiving 15 tons produce 188 per cent; or the average increase per ton of manure applied is twice as great when 5 tons are applied as when three times that much is used.

Considering the average of the soil receiving no irrigation water as 100 per cent, the others then become with 5 inches of water, 106 per cent; with 10 inches of water, 117 per cent; 20 inches of water, 108 per cent; 30 inches of water, 106 per cent; and 40 inches of water, 108 per cent. The greatest increase in ammonifying powers results from the application of 10 inches of irrigation water.

The nitrifying powers were determined as previously outlined, and the results reported in Table VI represent milligrams of nitric nitrogen formed during 21 days in 100 gm. of soil containing 2 gm. of dried blood. The results as reported are the average in each case of a number of determinations taken during two years.

TABLE VI.—*Quantity of nitric nitrogen (in milligrams) produced in 21 days in 100 gm. of soil to which had been added 2 gm. of dried blood—fallow plots*

Number of determinations.	Treatment.	Quantity of nitric nitrogen.			
		May 12.	July 25.	Nov. 12.	Average.
12	No water; no manure	1.46	16.36	2.16	6.66
6	5 inches water; no manure	1.40	11.90	.88	4.72
6	10 inches water; no manure	.79	13.85	.97	5.20
6	20 inches water; no manure	1.19	13.30	1.33	5.27
6	30 inches water; no manure	1.40	9.27	1.00	3.89
9	40 inches water; no manure	1.05	5.37	.89	2.43
6	No water; 5 tons of manure	1.47	10.32	2.15	4.64
6	No water; 15 tons of manure	11.90	40.43	30.50	27.61
3	5 inches water; 5 tons of manure	4.03	4.20	7.35	5.19
3	5 inches water; 15 tons of manure	1.75	45.20	31.85	26.27
3	10 inches water; 5 tons of manure	1.47	24.85	.70	9.01
3	10 inches water; 15 tons of manure	2.63	26.25	15.40	14.76
3	20 inches water; 5 tons of manure	1.23	7.70	11.20	6.71
3	20 inches water; 15 tons of manure	2.53	40.95	18.90	20.79
3	30 inches water; 5 tons of manure	.88	2.80	2.80	2.16
3	30 inches water; 15 tons of manure	2.52	21.00	46.90	23.47
9	40 inches water; 5 tons of manure	1.19	2.33	2.22	1.91
6	40 inches water; 15 tons of manure	2.63	25.78	33.65	20.00

All of these results will appear low when compared with those obtained by many other workers, who report their results as milligrams of nitrates found. The nitrifying powers of all the soils are low in the spring, but become much higher in midsummer and fall back in autumn to about where they were in the spring.

During the spring the nitrifying powers of the soil vary with the manure applied. But the difference existing between the manured and unmanured soil in no case is great. The irrigation water which had been

applied during the previous season exerted no effect which carried over the winter. In midsummer the nitrifying powers of the soil receiving 5 tons of manure are apparently less than the soil receiving no manure. The plots receiving 15 tons per acre are much more active in nitrifying dried blood than are the others. The lower applications of irrigation water apparently exert a favorable influence on all the plots, but the greater applications exert a depressing influence. It is, however, no more marked in the heavily manured soils than in the others; therefore, if there be any denitrification taking place, it must be attributed to the production of anerobic conditions by the water, and not due to the manure applied. In November the beneficial influence of the 5 tons of manure applied becomes more regular than at any other time of the year. Here also the influence of the water becomes more perceptible. Taking the results as a whole they do not show the influence of either manure or water as well as it was shown by the potted soils; nor do they bring out the difference as clearly as it is brought out by the ammonification series. The relationship actually existing in the various treated soils is brought out graphically in figure 5.

On the base line is indicated the irrigation water applied in inches per acre, while on the perpendicular line is given the milligrams of nitric nitrogen produced in 100 gm. of soil to which 2 gm. of dried blood had been added. Taking the average nitric nitrogen produced in the unmanured soil as 100 per cent, the soil receiving 5 tons of manure becomes 105 per cent, while that of the soil receiving 15 tons becomes 486 per cent; or the average increase per unit of manure applied is much greater when 15 tons of manure are applied than when only 5 tons are applied. In this respect it differs markedly from the ammonification series.

Taking the average of the unirrigated plots as 100 per cent, the irrigated plots then arrange themselves in the order—5 inches, 94 per cent; 10 inches, 75 per cent; 20 inches, 85 per cent; 30 inches, 76 per cent; and 40 inches, 65 per cent. In every case the average for the season on all plots shows the water to have a depressing influence upon nitrification.

FIELD EXPERIMENTS ON CROPPED PLOTS

The same number of plots, arranged and treated exactly the same as those in the preceding part except that they were cropped, were sampled. These had grown corn continuously since the spring of 1911. They were sampled at the same time of the year, and bacterial counts made as was done on the fallow soil. The average results are given in Table VII.

These results are very similar to those obtained on the fallow soil. The number of organisms obtained is slightly lower and we do not find as great an increase during the summer months as we do on the fallow. The count as obtained in the spring is low for the unmanured soil, higher for that receiving 5 tons per acre of manure and still higher for the soil receiving 15 tons of manure. While the difference is marked,

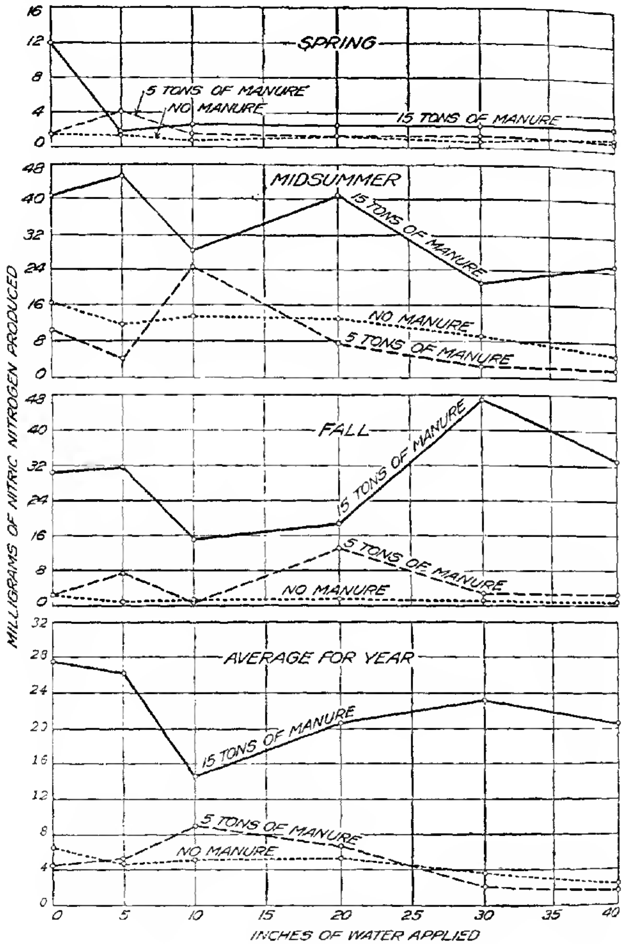

FIG. 5.—Curves of the nitrifying powers of fallow soil with varying quantities of manure and water.

it is not as pronounced as it is in the fallow soil. The same general order is seen during spring and fall, but in the fall the difference is greater in degree and more regular than in the earlier part of the year. The application of irrigation water produces an increase with the lower applications, especially on the heavily manured soil. The irregularity of this set as compared to the fallow can be accounted for in a degree by the error entering in sampling, for in some cases the sample may be taken nearer a plant than in others and in the cultivation and irrigation the tendency would be to leave the soil less homogeneous in the cropped than in the fallow plots. These conditions were borne in mind at the time of sampling and efforts made to get representative samples, but the results show that much more care must be taken on cropped than on fallow soil. The results for this series of plots are given graphically in figure 6.

TABLE VII.—*Number of colonies of bacteria developing in four days on synthetic agar—cropped plots*

Number of determinations.	Treatment.	Number of colonies.			
		May 20.	Aug. 9.	Nov. 8.	Average.
6	No water; no manure..	4,300,000	7,300,000	4,000,000	5,200,000
6	5 inches of water; no manure......... ...	4,500,000	4,250,000	2,700,000	3,817,000
6	10 inches of water; no manure..............	5,800,000	3,950,000	1,800,000	3,850,000
6	20 inches of water; no manure..............	5,200,000	6,150,000	1,800,000	4,387,000
6	30 inches of water; no manure..............	5,100,000	4,600,000	2,000,000	3,900,000
6	40 inches of water; no manure..............	4,300,000	4,700,000	5,700,000	4,900,000
6	No water; 5 tons of manure......	8,300,000	4,700,000	3,200,000	5,400,000
6	No water; 15 tons of manure..............	5,300,000	5,400,000	2,200,000	4,300,000
6	5 inches of water; 5 tons of manure...........	6,300,000	5,300,000	2,900,000	4,833,000
6	5 inches of water 15 tons of manure.	8,800,000	6,950,000	6,800,000	7,517,000
6	10 inches of water; 5 tons of manure......	6,100,000	6,300,000	7,800,000	6,733,000
6	10 inches of water; 15 tons of manure......	6,800,000	5,800,000	4,200,000	4,933,000
6	20 inches of water; 5 tons of manure.....	6,100,000	6,350,000	4,500,000	5,633,000
6	20 inches of water; 15 tons of manure......	5,900,000	5,450,000	4,600,000	5,317,000
6	30 inches of water; 5 tons of manure......	4,200,000	6,900,000	2,800,000	4,633,000
6	30 inches of water; 15 tons of manure......	5,800,000	6,900,000	3,800,000	5,500,000
6	40 inches of water; 5 tons of manure......	7,600,000	4,450,000	3,500,000	5,183,000
6	40 inches of water; 15 tons of manure......	5,100,000	7,000,000	7,800,000	6,633,000

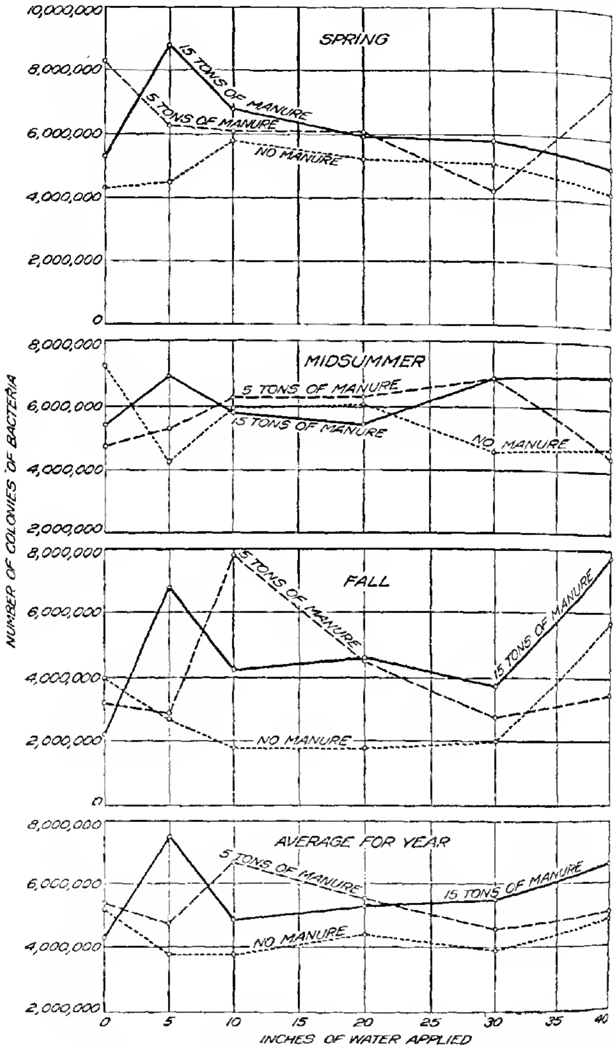

Fig. 6.—Curves of the number of colonies of bacteria developing from cropped plots with varying quantities of manure.

If the average number of bacteria found in the manured soil be taken as 100 per cent, the soil receiving 5 tons of manure then becomes 123 per cent and that receiving 15 tons, 129 per cent. Taking the average bacterial count of the plot receiving no irrigation water as 100 per cent, the others then become with 5 inches of water, 109 per cent; with 10 inches of water, 104 per cent; with 20 inches, 103 per cent; with 30 inches, 94 per cent; and with 40 inches, 112 per cent. With one exception the irrigation water had increased the number of bacteria in the soil.

The same plots were analyzed on the same dates for their ammonifying powers, and the results are given in Table VIII as milligrams of ammonia produced in four days in 100 gm. of soil, to which were added 2 gm. of dried blood. Each result is the average of a number of closely agreeing determinations.

TABLE VIII.—*Quantity of ammonia (in milligrams) formed in four days in 100 gm. of soil containing 2 gm. of dried blood—cropped plots*

Number of determinations.	Treatment.	Quantity of ammonia.			
		May 10.	Aug. 9.	Nov. 8.	Average.
6	No water; no manure	54.05	44.54	46.59	48.39
6	5 inches of water; no manure	48.96	49.64	45.73	48.11
6	10 inches of water; no manure	50.10	51.17	44.54	48.60
6	20 inches of water; no manure	53.04	48.27	39.95	47.09
6	30 inches of water, no manure	48.96	45.05	36.89	43.63
6	40 inches of water; no manure	52.87	51.55	37.07	47.16
6	No water; 5 tons of manure	57.80	67.15	55.25	60.07
6	No water; 15 tons of manure	71.69	67.15	68.85	69.23
6	5 inches of water; 5 tons of manure	60.33	60.69	53.17	58.06
6	5 inches of water; 15 tons of manure	91.63	74.41	73.79	79.94
6	10 inches of water; 5 tons of manure	61.08	70.69	61.54	64.44
6	10 inches of water; 15 tons of manure	92.90	89.93	87.05	89.99
6	20 inches of water; 5 tons of manure	63.16	61.54	56.10	60.26
6	20 inches of water; 15 tons of manure	96.60	101.15	89.45	95.76
6	30 inches of water; 5 tons of manure	57.07	68.17	51.34	59.16
6	30 inches of water; 15 tons of manure	97.41	115.20	76.16	96.26
6	40 inches of water; 5 tons of manure	65.07	67.40	51.01	60.52
6	40 inches of water; 15 tons of manure	80.87	91.63	77.20	83.23

The ammonifying powers of these soils are lower, as an average, in the cropped than in the fallow soil. The average quantity of ammonia produced by the fallow soil was 79.43 mgm., while that produced by the cropped soil was 64.48 mgm. The variation due to seasonal differences is not as great in the cropped as in the fallow soil, thus indicating that the influence of the season on the rate of ammonification is greatly offset

by crop and cultural methods. The variation between the differently treated soils during the same part of the year is qualitatively similar to that noted in the fallow soil.

The influence of the manure is very pronounced throughout the entire season. The ammonifying powers of the unmanured soils are all low, while those of soils receiving 5 tons of manure per acre are higher. Those of soils receiving 15 tons of manure per acre are very high. This difference is probably slightly greater during the spring months than during the fall.

The irrigation water applied is found to exert an influence upon this group of bacterial activities. Measured in terms of ammonification, the unmanured soils and those receiving 5 tons of manure per acre are benefited greatly by small quantities (10 and 20 inches) of irrigation water, while the soils receiving 15 tons of manure per acre have the highest ammonifying powers when they receive 20 or 30 inches of water. During the spring it is greatest in those soils from plots receiving 30 inches of irrigation water. Forty inches of water produce a marked depression in the ammonia formed, being pronounced in the soils receiving 15 tons of manure not only in the cropped soil but also in the fallow and potted soils. It is clear, therefore, that large quantities of water applied to a soil rich in organic matter depress the beneficial bacterial activities of that soil. The fallow unmanured soils and soils receiving 5 tons of manure per acre showed a slight decrease in the ammonifying powers of the soil, owing to the larger applications of irrigation water; but this does not appear in the cropped soil and is probably caused by the removal of large quantities of water by the growing crop, so that enough water does not accumulate in the presence of these small quantities of organic material to injure the ammonifying powers of the soil. These facts are brought out clearly in figure 7.

If we take the average of the quantity of ammonia produced in the unmanured soil as 100 per cent, the others then become with 5 tons 129 per cent and with 15 tons 183 per cent. Here the average increase per ton of manure applied is about the same whether 5 or 15 tons of manure be applied per acre. If the average of the plots receiving no irrigation water be taken as 100 per cent, the others then become with 5 inches of water 105 per cent; with 10 inches, 114 per cent; 20 inches, 118 per cent; 30 inches, 112 per cent; and 40 inches, 109 per cent. It thus reaches its maximum when 20 inches of water are applied, while the fallow reached its maximum when only 10 inches were applied. This is a difference which is undoubtedly due to the great quantities of water removed by the growing plant. The average increase per acre-inch of water, however, is greatest in the cropped soil where only 10 inches of irrigation water were applied.

The nitrifying powers of the same soils were tested by the method previously given, the results of such tests being given in Table IX as milligrams of nitric nitrogen produced during 21 days in 100 gm. of

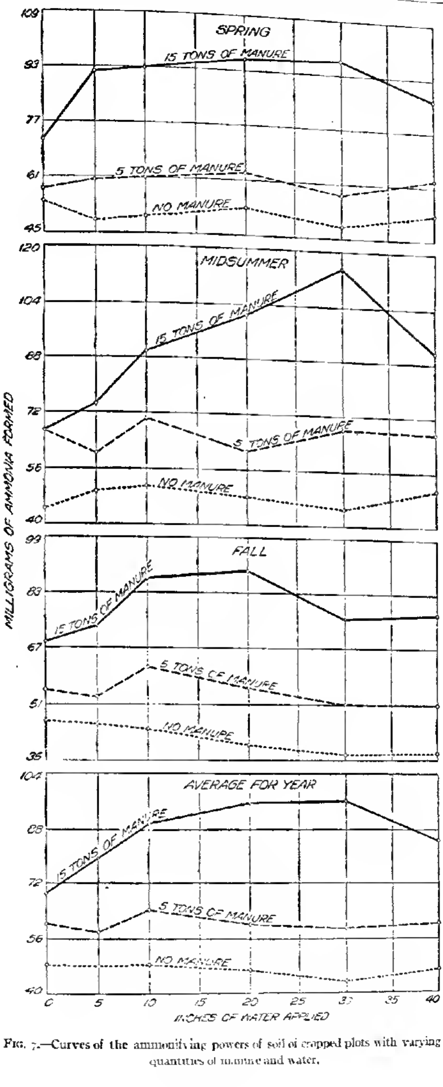

FIG. 7.—Curves of the ammonifying powers of soil of cropped plots with varying quantities of manure and water.

soil containing 2 gm. of dried blood. All the reported results are the average of two or more closely agreeing determinations.

TABLE IX.—*Quantity of nitric nitrogen (in milligrams) formed in 100 gm. of soil containing 2 gm. of dried blood*

Number of determinations.	Treatment.	Quantity of nitric nitrogen.			
		May 10.	Aug. 9.	Nov. 8.	Average.
6	No water; no manure	1.50	1.33	0.84	1.22
6	5 inches of water; no manure	3.47	.81	.88	1.72
6	10 inches of water; no manure	2.27	.56	.53	1.12
6	20 inches of water; no manure	1.05	.50	1.85	1.13
6	30 inches of water; no manure	1.40	.38	.35	.71
6	40 inches of water; no manure	2.10	.70	1.15	1.31
6	No water; 5 tons of manure	1.65	1.80	2.45	1.97
6	No water; 15 tons of manure	45.32	8.85	27.52	27.23
6	5 inches of water; 5 tons of manure	20.30	.53	3.43	8.08
6	5 inches of water; 15 tons of manure	46.80	2.66	33.65	27.70
6	10 inches of water; 5 tons of manure	4.90	.58	8.48	4.65
6	10 inches of water; 15 tons of manure	47.45	2.27	22.92	24.21
6	20 inches of water; 5 tons of manure	9.27	.63	2.66	4.18
6	20 inches of water; 15 tons of manure	53.05	2.17	23.80	26.34
6	30 inches of water; 5 tons of manure	12.30	.40	2.80	5.17
6	30 inches of water; 15 tons of manure	60.25	15.46	4.93	26.88
6	40 inches of water; 5 tons of manure	18.37	.45	6.75	8.52
6	40 inches of water; 15 tons of manure	37.05	1.01	14.08	17.38

The nitrifying powers of these soils are uniformly higher in the spring months of the year than later. This occurs in all the plots, but the greatest difference is found in the heavily manured plots, due probably to the application of large quantities of readily nitrifiable material in the manure, which is transformed later into soluble nitrates taken up by the growing plant, removed in the drainage water, or transformed into complex protein substances within the bodies of various microorganisms. The results taken as a whole bear a very great similarity to those obtained on the fallow soil. They are, however, as were the counts and ammonifying powers, slightly higher in the fallow than in the cropped soil.

The nitrifying powers of the unmanured soil are low throughout the year. The nitrates produced by the manured soil increase with the increase of manure applied. The greatest difference, however, exists between the soil receiving 5 and 15 tons of manure per year. In the latter the nitrifying activity is extremely active in the spring months. This difference, while not as pronounced later in the year, exists throughout the season.

The irrigation water exerts a great influence upon the nitrifying powers of the soil and this follows almost exactly the order followed by the ammonifying series. It is greatest when a medium amount of water is applied, but becomes injurious as greater quantities of water are applied to the soil, especially with large quantities of organic matter. One could not conclude from these results that the quantities of water here applied in the presence of organic manure favor denitrification, but it is certain that the conditions thus produced are not the best for the nitrate and ammonia-forming organisms, and it is quite likely due to the anerobic condition produced by the excess of water. It is interesting to note that larger quantities of water are required on a cropped soil to exert this depressing influence than on a fallow soil. The results for this series are given graphically in figure 8.

Taking the average quantity of nitric nitrogen produced in the unmanured soil as 100 per cent, the soil receiving 5 tons of manure then becomes 453 per cent, while the percentage produced in the soils receiving 15 tons per acre becomes 2,079. Thus, an enormous increase is due directly to the application of manure to the soil.

Taking the average quantity of nitric nitrogen produced in the soil receiving no irrigation water as 100 per cent, the irrigated soils produced with 5 inches of water, 126 per cent; with 10 inches of water, 99 per cent; 20 inches of water, 104 per cent; 30 inches of water, 108 per cent; and 40 inches of water, 89 per cent—an unmistakable reduction in the nitrifying powers of soils receiving 40 inches of irrigation water.

RELATIONSHIP IN BACTERIAL ACTIVITIES IN POTTED, CROPPED, AND UNCROPPED SOIL

If we use in every case the quantity of ammonia and nitric nitrogen produced and the total number of bacteria developing from the unmanured in the one case and the unirrigated in the other as 100 per cent, we have a direct comparison between the bacterial activities of the variously treated soils. The results so obtained are given in Table X.

TABLE X.—*Comparison of the bacterial activities in the potted, fallow, and cropped soils*

Treatment.	Bacteria.			Ammonia.			Nitric nitrogen.		
	Pots.	Fallow.	Cropped.	Pots.	Fallow.	Cropped.	Pots.	Fallow.	Cropped.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
No manure	100	100	100	100	100	100	100	100	100
5 tons of manure	99	144	123	122	147	120	1,211	105	453
15 tons of manure	100	177	120	152	188	183	2,240	486	2,079
No irrigation water	[a] 100	100	100	[a] 100	100	100	[a] 100	100	100
5 inches of water	[b] 90	81	100	[b] 111	106	105	[b] 118	94	126
10 inches of water	[c] 91	106	104	[c] 113	117	114	[c] 121	75	99
20 inches of water	[d] 70	107	103	[d] 125	108	118	[d] 121	85	104
30 inches of water	[e] 87	110	94	[e] 110	106	112	[e] 123	76	108
40 inches of water	......	91	112	.....	107	108	......	65	89

[a] 12.5 per cent applied.
[b] 15 per cent applied.
[c] 17.5 per cent applied.
[d] 20 per cent applied.
[e] 22.5 per cent applied.

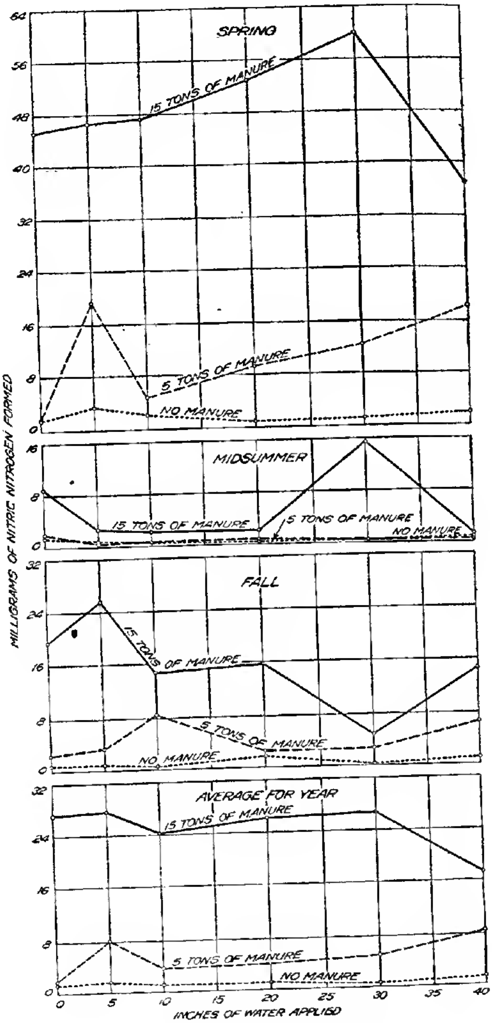

FIG. 8.—Curves of the nitrifying powers of soil of cropped plots with varying quantities of manure and water.

The results for manure show a remarkable uniformity throughout. With one exception it has increased the bacterial count and also the bacterial activities of the soil, and this is about the order throughout. The ammonifying and bacterial counts are increased more by the manure in the fallow than in the cropped soil.

The irrigation water applied apparently increases the bacterial count in the fallow and cropped field soil but it apparently depresses it in the potted soil. The ammonifying powers of all soils are uniformly increased with increasing amounts of irrigation water applied up to a certain application. Above this there is a depression. Greater quantities of water must be applied to cropped than uncropped soil in order to cause this depression. This is mainly owing to the influence of the plant upon the moisture content of the soil.

The nitrifying powers of the potted soils are very uniform in showing a beneficial effect due to the water. The cropped soil is not so uniform, while the fallow soil shows a depressing influence. These apparently contradictory results are quite likely caused by a difference in treatment, for the water in the three different sets of soil may have been far from the same.

RELATIONSHIPS BETWEEN BACTERIAL ACTIVITIES AND CROP-PRODUCING POWERS

The results herein reported, together with those published by Dr. Harris (19) upon Greenville soil, make it possible to compare directly the crop produced on the soil as an average of five years with the bacterial activities of the soil. This is done in figures 9 and 10, in which the bacterial activities and crop-producing powers of the unmanured soil are taken as 100 per cent and each of the manured plots compared with this. In the case of water applied the bacterial activities and crop produced upon the soils receiving no irrigation water are taken as 100 per cent and the others compared with this.

An examination of figure 9 shows a remarkably close correlation between the crop produced and the bacterial activities of the soil. The extent to which the bacterial count and ammonifying powers of the soil are increased by the manure applied is almost quantitatively the same as the increase in the crop produced on the manured soil. The increase in the nitrifying powers of the soil is much greater than the crop increase due to manure, but they are all of the same order.

An examination of figure 10 reveals the fact that the application of 5 inches of irrigation water increases in nearly the same proportion the crop produced and the bacterial activities of the soil. The average percentage for the crop is 112, while the total average bacterial activities is 113 per cent. The crop produced on the soil receiving 10 inches of water is slightly less than that produced on the soil receiving 5 inches

of irrigation water. With the exception of the ammonia produced, the bacterial activities are not as high in the soil receiving 10 as in the soil receiving only 5 inches of irrigation water. The average percentage of the crop produced on this is 110, while the average of the bacterial activities is 102 per cent. The application of 20 inches of irrigation water greatly increased the crop produced and also the bacterial activities, the crop produced being 127 per cent compared with the unirrigated, while using the same comparison for bacterial activities gives 108 per cent. The application of 30 inches of irrigation water causes a slight decrease in the corn produced and also in the bacterial activities of the soil, 40 inches of irrigation water producing about the same crop as did 30 inches. But it caused a slight falling off in the bacterial activities of the soil, especially in the nitrifying powers of the soil. Taking the result as a whole, we find that the bacterial activities of the soil and the crop-producing powers of a soil are both influenced by the application of irrigation water and this in the same direction and in about the same degree. These results tend to indicate that the bacteriological analysis of a soil gives a fair insight into its relative crop-producing powers, being especially true with regards to the ammonifying and nitrifying powers of the soil.

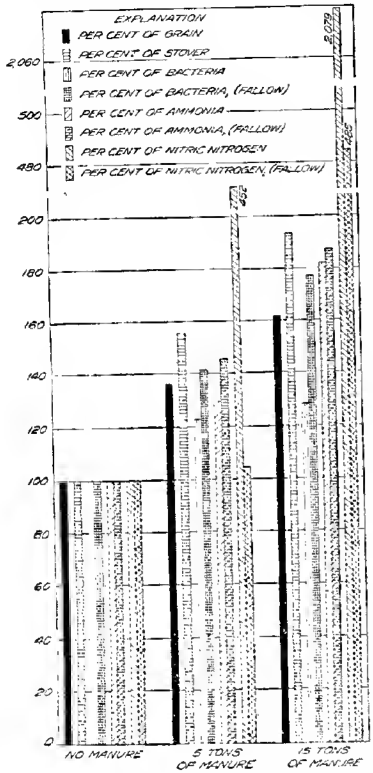

FIG. 9.—Diagram of the influence of manure on the yield and bacterial activities of a soil, the unmanured plots being expressed as 100 per cent.

SUMMARY

A calcareous soil kept in pots with varying amounts of manure and different percentage of moisture gave on bacteriological analyses at the end of four months the following results.

The temperature of the manured and unmanured averaged practically the same for the period, but the temperature of the soil with 12.5 per cent of water averaged 1 degree centigrade higher than did soils with 22.5 per cent of water. The greatest number of organisms developed on synthetic media from the soils receiving the greatest quantity, 25 tons, of manure. There were more colonies developed from the soil receiving 12.5 per cent of water than from any of the other soils receiving higher quantities of water.

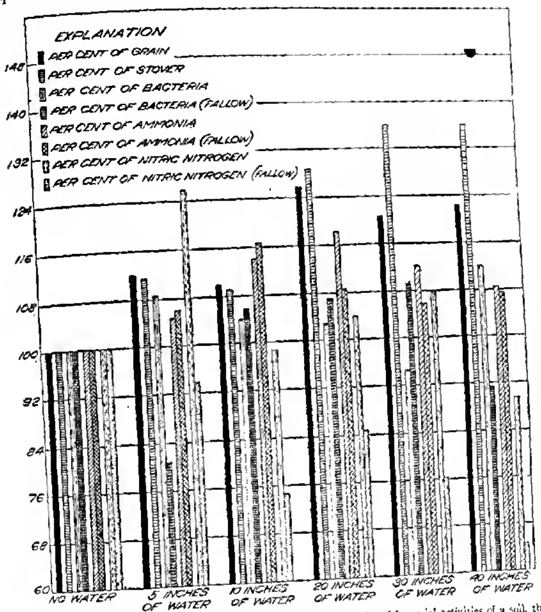

FIG. 10.—Diagram of the influence of irrigation water on the yield and bacterial activities of a soil, the nonirrigated plots being expressed as 100 per cent.

The ammonifying powers of the soil increased with the manure applied up to 25 tons of manure per acre, but the greatest increase per ton of manure was obtained in soil receiving 5 tons.

The ammonifying powers of the soils increased as the water applied increased until 20 per cent of water was applied. The ammonifying powers of soil receiving 22.5 per cent of water were not as high as were those of soil receiving 20 per cent of water. The greatest increase per unit of water applied was when the water was increased from 12.5 to 15 per cent of water.

The nitrifying powers of the soil increased as the manure and water applied increased up to 25 tons of manure and 22.5 per cent of water.

The nitrogen-fixing powers of the soil were greatest in those pots receiving at the rate of 10 tons of manure per acre. Increasing the water above 12.5 per cent but not above 22.5 per cent slightly increased the nitrogen-fixing powers of the soil. Nothing in the results indicated that the application of manure up to 25 tons per acre and of water up to 22.5 per cent caused denitrification in the soil.

Bacteriological analyses of fallow field soil receiving none, 5 tons, and 15 tons of manure per acre and receiving none, 5 inches, 10 inches, 20 inches, 30 inches, and 40 inches of irrigation water gave the following results.

The maximum number of bacteria were obtained from the soil receiving 15 tons of manure. The application of irrigation water up to 20 inches increased the bacterial count, being most noticeable in the soil receiving the greatest quantity of manure.

If the ammonifying powers of the unmanured soils are considered as 100 per cent and the unirrigated as 100 per cent, the manured and irrigated soils then become with 5 tons of manure, 147 per cent; with 15 tons of manure, 188 per cent; 5 inches of water, 106 per cent; 10 inches of water, 117 per cent; 20 inches of water, 108 per cent; 30 inches of water, 106 per cent; and 40 inches of water, 108 per cent. Large quantities of irrigation water produced the greatest depressing effect in the presence of 15 tons of manure per acre.

The application of manure to a soil increases its nitrifying powers. The application of irrigation water to a fallow soil apparently depresses its nitrifying powers.

Fewer organisms develop on synthetic agar from a cropped than from a fallow soil. The application of manure to a cropped soil increases the bacterial count of the soil. The greatest number of organisms developed from the soil receiving 10 inches of irrigation water.

The ammonifying powers of the cropped soils were slightly lower than similarly treated fallow soils. The application of 5 and 15 tons of manure per acre to a soil increases the ammonifying powers of the soil. The application of irrigation water up to 30 inches increases the ammonifying powers of the soil. The greatest increase resulted in those soils receiving 15 tons per acre of manure. The application of 40 inches of irrigation water to corn land, especially to that receiving 15 tons of manure per acre, depresses the ammonifying powers of the soil.

The nitrifying powers of fallow soil were higher than similarly treated cropped soils. The application of manure to a cropped soil greatly increases its nitrifying power. The application of irrigation water up to 30 inches, especially to a soil receiving 15 tons of manure per acre, greatly increases its nitrifying powers.

There was found to be a direct relationship between the bacterial count, the ammonifying powers, the nitrifying powers, and the crop produced on a soil receiving no manure, 5 tons, and 15 tons of manure per acre.

A close correlation was also found to exist between the bacterial activities of soil receiving varying amounts of water and crop produced upon the soil.

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